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ASPECTS OF VOCAL FUNCTION IN MALE ADOLESCENT CHORISTERS

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Statement

I, Daphne Jill Pearce, confirm that the work presented in this thesis is my own. Those investigations I am not qualified to undertake were undertaken by the appropriate specialists at St. Bartholomew's Hospital, London.

Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

ASPECTS OF VOCAL FUNCTION IN MALE ADOLESCENT CHORISTERS

ABSTRACT

This study arose from a need to obtain more information on characteristics of vocal function to guide the clinical management of voice problems in pre-pubescent and pubescent choristers.

The key aims were:-

- To establish some normative data for male adolescent choristers
- To explore the relationship between fundamental frequency and the parameters of chronological age and biometric features.
- To identify features which may predict vocal maturation

From this information it sought to identify the characteristics of vocal function of male adolescent choristers aged 8 years to 13 years, and to assess the influence of physiological changes and vocal training.

The study was designed as a longitudinal study of boys from a Cathedral Choir School. The study group diminished as senior boys left the school.

Forty boys were assessed at the outset, thirty of that group after one year, and twenty remaining one year later. The procedure was complex involving the co-ordination of several departments in a NHS hospital as well as the Cathedral Choir School. The protocol included:-

Lung Function measurements

Biometric and Audiometric Screening

ENT examination

Voice fundamental frequency measurements for a range of tasks using electrolaryngography.

In addition the boys completed a lifestyle questionnaire.

The relationship between voice fundamental frequency measures derived from a range of materials, is related to biometric data. Issues involved in obtaining these measurements from children and the relevance to clinical management of dysphonia, and to their vocal training are discussed.

The results are presented with reference to any relationships among the parameters. The limitations of the study are identified and discussed. The findings highlight the vast spectrum of vocal behaviours and the importance of evaluating vocal behaviour as well as vocal function.

ACKNOWLEDGEMENTS

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The data collection was completed with the assistance of staff in the ENT, Audiology, Respiratory Medicine and Child Health Departments at St. Bartholomew's Hospital London, who found time during their already hectic schedules to complete the various investigations. In particular I wish to acknowledge the expertise, experience and wisdom of Mr Malcolm Keene, Consultant ENT Surgeon at St. Bartholomew's Hospital for all the help and support he has always given me in all aspects of my work.

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Above all I thank my parents for their constant and absolute support, and the opportunities they have made possible for me.

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GLOSSARY

CFx	A single diagonal distribution crossplot derived from the electrolaryngograph. where Fx1 is the frequency value of the first vocal fold cycle in any pair of cycles and Fx2 is the frequency value of the immediately following cycle of the pair.
Dx	The distribution of excitation fundamental frequencies computed from logarithmically equal bins from 30 – 1000Hz.
DFx1	The probability distribution for the frequency of every vocal fold cycle.
DFx2	The second order distributions. These consist of the Lx cycles which fall into the same bin as the adjacent cycle.
EGG	Electroglottography: The generic term for electrical impedance monitoring of the vocal fold vibratory cycle.
ELG	Electrolaryngography: A non-invasive method of electrical impedance monitoring of the closed phase of the vocal fold vibratory cycle using gold-plated electrodes placed externally on the thyroid cartilage.
Fo	The rate of repetition of a waveform per unit time measured in Hz.
Fx	The period-by-period frequency measured by the electrolaryngograph.
Hz	Hertz. A measurement of unit for frequency that is equal to the number of cycles per second of a waveform.
IDL	Indirect laryngocopy; a techinique to examine the larynx using a mirror or an endoscope.
Lx	The output waveform from the laryngograph relating to the opening and closing of the vocal folds as a function of time. Fundamental frequency and closed quotient are measured from this waveform.
Qx	Closed Quotient ratio calculated by the laryngograph from measurement of the width of the peaks of the Lx waveform 70% below the point of maximum closure.
SFF	Speaking fundamental frequency.
S/T	Semitone; half a tone on a musical scale.
VOT	Voice onset time; related to articulator-laryngeal co-ordination defined as " the interval between the release of an oral constriction and the start of glottal pulsing."

PART I

CHAPTER 1 INTRODUCTION

1 *Background to the Study*

The singing voice is a complex phenomenon, embracing at least three key elements; perceived sound with its measurable acoustic properties; the larynx as the sound source with a clearly identified structure and function, and expression – the variable that ultimately determines the perceptual qualities and defies simple definition.

Writing on `The Origin and Function of Music' Confucius states:-

> *"Music rises from the human heart when the human heart is touched by the external world. When touched by the external world, the heart is moved, and therefore finds its expression in sounds."*

Therein lies the question which is fundamental to any study of voice and vocal function. Given the dynamics of voice use, to what extent is it possible and how appropriate is it to separate the components, and, specifically, to isolate the acoustic features or any one level of representation?

Advances in technology have enabled the study of voice production to develop from an imprecise art to an increasingly refined science. The use of nasendoscopy and videostroboscopy facilitates more accurate evaluation of the structures of the larynx than was possible by mirror examination. Examination of the larynx provides information to enable identification of the causative anatomical or physiological factor, or factors to account for the symptom of vocal dysfunction. The causes may be varied and complex; they may be conspicuous or more obscure necessitating a multi-modal approach. Some perceptual characteristics and limitations of function can be directly related to pathological change of the vocal folds, as for example in Reinke's oedema, an inflammatory condition, which in turn may be attributable to behaviours (eg. a cigarette smoking habit); often it is not so obvious. The complementary use of electrolaryngography (ELG) provides more objective physical measurement of aspects of sustained phonation and continuous speech.

Measurement of the acoustic parameters of fundamental frequency (Fo), (mean, mode, median and range) can be correlated with age and gender. This information is important to establish the extent to which vocal function deviates from the norm and to evaluate the outcome of clinical intervention.

In many instances the feature which has been identified as abnormal or atypical of the individual's voice is Fo. This applies particularly to singers who will often report a restricted range, difficulty reaching a particular register, or a discrete lowering of the habitual pitch of their speaking voice before they are aware of any change in their performing voice. Although subjective judgements, especially by a trained ear, provide useful information, decisions to provide effective management, whether clinical intervention or voice training, should ideally be based on other forms of data as well.

1.1 ***Reason for the Study***

"Would you tell me please, which way I ought to go from here?"
"That depends a good deal on where you want to get to," said the Cat.
(Lewis Carroll. Alice's Adventures in Wonderland 1896)

Clinical practice often reveals trends. Clusters of people presenting certain symptoms or diseases, or increased incidences act as a catalyst not only for publicity such as accompanies out-breaks of e-coli or meningitis, but also for investigation of contributory or causative factors.

A change in referral activity prompted questions which led to this study. A chorister from a London cathedral was referred to the ENT clinic at The Royal Hospital of St. Bartholomew, London, because he was having difficulty singing. There was no record of any previous referral of choristers but this referral heralded what became a steadily increasing incidence of choristers presenting with vocal dysfunction.

The voice of the adolescent male chorister provokes an assortment of emotion from ecstatic delight at the exquisite sounds, to vociferous condemnation of what may be perceived as exploitation. However, the clinician charged with remediation of dysphonia has a very clear remit; assessment, diagnosis and clinical management as appropriate. It was apparent that in order to provide optimal care to these young boys, preferably including preventative care, more information was required than was currently available on this specific group.

Reference to studies of normal and pathological adult voice demonstrates the number of factors which influence vocal function and the many variables which must be taken into account. What constitutes normal voice still remains a most challenging question which has to take account of two aspects; (i) measurement of the vocal fold vibratory cycle which can be compared to normative data for a particular subject group, and (ii) determining whether the perceptual feature of vocal quality is 'normal'.

1.2 *Features of studies of 'normal' voice.*

Reference to the wealth of material on 'normal' adult voice suggests findings may be applicable only to the specific subject group examined at a particular time under given conditions.

Studies of adult populations can select subjects according to defined criteria, (Bless et al 1993. McGlone and Hollien 1963. Ptacek et al 1966). Hollien at al (1971), for example, reported on the adult phonational range of randomly selected subjects but excluded those who had any singing training, health problems or speech disorders. The age span of 18years-36years was considered acceptable in defining an adult population; however, since the subjects were mainly university staff and students the findings are representative of this group and not necessarily applicable to a broader population.

As well as accountable differences, interspeaker variations of vocal function are frequently evident indicating a need for studies of large groups to establish norms which can be considered reliable and demonstrate patterns which represent normal function, noted by Holmberg et al. (1988), but still relevant as advances in technology allow more understanding of the characteristics of normal function.

In practical terms the number of variables evident in cross sectional studies can be so great that generalisation of findings is not meaningful, and that studies of specific groups with a number of common variables are more useful.

1.2.1 *Perceptions of 'normal' voice*

Perceptions of whether a voice sounds 'normal' is influenced by subjective judgements. These judgements are affected by numerous factors; the way in which an individual construes those factors is based on comparison of what is heard with their internal reference of normal voice and in relation to their needs. An individual may not notice a change in the sound of his voice but becomes aware that it cannot be used in the same way; for example a teacher may report that (s) he cannot make himself heard at the back of the class; a singer may find the vocal range reduced. Children however are unlikely to draw attention to any vocal difficulties – even if they are aware themselves - which are not typically associated with any discomfort. Since shouting is usually regarded as a normal behaviour in children if any changes in vocal function are observed they are often disregarded as something the child 'will grow out of'; however, White (2000) suggests habits of voice use which are established in childhood may persist .

1.3 *Historical Background*

"The dream of every Viennese is to be born
as a chorister and die as a Lipizzaner."
(Attributed to Karl Kraus. Austrian Satirist. 1874 – 1936)

Whilst the objective of this study is to make a quantitative evaluation of aspects of vocal function in male adolescent choristers, the findings cannot and should not be divorced from the more complex and potentially contentious issues relating to the boys' welfare. This is put into context by reference to the historical background to this very particular aspect of modern society.

In his definitive text on 'The Pubertal Change of the Human Voice', Weiss (1950) refers to the fascination provoked by boy's voices. In ancient Rome infibulation (encasing the sexual organs in a metal sheath) was practised in an attempt to prevent the loss of the sensually innocent voice. Koenigsberger (1987) refers to Clement of Alexandria (d 215) questioning the morality of early Church music calling that. *"It must be banned, this artificial music which injures souls and draws them into feelings snivelling, impure and sensual, and even a Bacchic frenzy and madness."* St.Augustine writing in his `Confessions' recorded *"When it happens to me to be more moved by the singing than by what is sung, I confess myself to have sinned criminally, and then I would rather not have heard the singing."*

Castration to conserve the singing voice was first documented in the 3rd C BC. More commonly associated with the Moslems' harem guards the practice was adopted first in Spain before being introduced in Italy. From 1562 singing castrati from Spain were sought after for choirs in Rome. In the 18th and 19th centuries an estimated four thousand boys were "prepared" annually, their voices being so valued that kidnapping, a common practice in the 11th century, still occurred. The public appearance of eunuch singers was first recorded in the 12thC by Theodore Balsemon, Canonist, in his *'Commentary'* on the *'Nomocanon'*. A papal bull by Sixtus V (1545-1590) provides evidence of castrati established in principal churches of the Iberian Peninsula. Although Barbier (1989), questions whether they were true castrati or falsettos, the registers of the Papal Choir in 1599 refers to entry to the choir of Pietro Paolo Folignati (Petrus Paulus Folignatus Eunuchus) and Girolamo Rasini of Perugia (Hieronigmus Rosinus Perusinus Eunuchus). The introduction of these singers caused Pope Clement VIII to consider the contemporary falsettos strident and forced and they were over time replaced with soprano castrati.

The subject of the selection of boys for castration and the rigorous training they underwent, usually for 6– 10 years is a fascinating – and sad - subject in its own right.

Castration was practised officially in hospitals and secretly in dispensaries and by barbers. Haemorrhaging and infection, often fatal, was not uncommon with an estimated mortality of up to 80% suggested. The procedure was usually performed between the ages of seven years and twelve years and involved the removal of the spermatic cord and testicles via an incision in the groin, with total removal by knife and the ducts tied. The removal of both testicles was essential for the procedure to be effective but differed from the excision of the entire sexual organs carried out on the eunuchs after puberty.

The medical profession also used castration in a misguided attempt to cure such ills as leprosy, epilepsy, gout and other conditions, including hernia. This was frequently the pretext used by Italian families in the "golden age of castrati singers" and in 1676 statistics from the Société Royale de Médecine cite over 500 boys castrated because of hernia in the diocese of Saint-Papoul near Carcassonne. The parents' motivation - to provide a means for their child to be removed from poverty to a musical education in the conservatoire, offering security and a degree of material comfort, and the prospect of a glittering future - is understandable. Although the police stipulated castration could only take place if the boy asked for it himself, no seven-year-old could reasonably be expected to understand the implications and many were told the procedure had been necessary because of a medical condition or accident.

So started a disciplined and rigorous training to develop their 'angelic' voices; a prized commodity. The quality achieved was unique to the castrati because although the vocal folds did not develop, the body, including the lungs developed fully, resulting in a powerful driving force and enabling remarkable breath control. The practice continued until it was banned in 1870 and in 1920 Pope Leo XIII decreed that singers who were physically "imperfect" were excluded from the Sistine Chapel; the last remaining castrato left in 1913 at the age of fifty five.

Pressure to identify how to preserve the infant voice continued with an interest in the process of change and differing opinions on voice use during the period of mutation. In the late 19th Century Sir Morrell Mackenzie, a laryngologist and voice physiologist, introduced the concept of health, describing singers as athletes as well as artists (Blatt 1983). Until this time it would appear that the boys' voices and vocal health had been in the domain of the choirmaster; a key factor, therefore, being music styles of the day. Until relatively recently females were excluded from Church choirs, *(Let your women keep silence in the churches: for it is not permitted unto them to speak; but they are commanded to be under obedience as also saith the law. 1 Corinthians 14.34),* although the appeal of the boy's voice was by no means limited to Church music. Van Oordt and Drost (1963) suggest that the use of children's voices by composers such as Bach, Bizet and Wagner resulted in the assumption that the child's voice was equivalent to a mature female voice.

All registers of male voice were popular in 17th Century Baroque Music and in the 18th Century the choirs featured sopranos, altos, tenors and basses, the sopranos being the unbroken voices and the altos most probably boys whose voices were breaking (Daw 1970). Daw describes a choir of 57; comprising 16 tenors and basses, 5 altos and 8 sopranos (unbroken voices). Most significantly the minimum age of an alto was 15 years; the maximum age 19 years.

However, in this era boys' voices rarely began to break before the age of 16 years, with an average age of voice beginning to break at 18 years and the average age of completed breaking of 17½years – 18½years.(Daw 1970) This trend mirrors that of overall physical growth generally attributed to environmental influences, such as nutrition. The rise in the average age of boys with alto voices at the Thomasschule in the mid 18th century was thought to have been the consequence of poverty inflicted by The War of Austrian Succession (1740-1748) with children's health badly affected and increased mortality in the school. The average age of voice breaking of London boys in 1959 was 13.3years (Daw 1970), a secular trend of approximately four years between 1740 and 1959, (Daw 1970). Hammarberg (1987) cites Schilling and Karthaus (1961) reporting mutation starting 1–2 years earlier than in 1900, with an increase of mean body length of approximately 11cm since 1929.

Although Sir Morrell Mackenzie was interested in health in relation to the maturation of the vocal apparatus he supported the idea of boys continuing, to some extent, to sing through the period of voice change. However, even at the turn of the 20^{th} century Dawson, a choirmaster, promoted boys continuing to sing and stated that it prevented the speaking voice breaking, (Blatt 1983).

An important consideration is therefore the age at which the boys' voice start to mature with children being brought in to the major choirs at a younger age because of the shorter 'lifespan' of their voice. Hollien et al (1994) identified the onset of adolescent voice change occurring in the majority of their subjects between the age of 12½ and 14½years, and current singing teachers advise pupils that the average age at which the voice starts to change is 12½years - although thirty years ago Kent (1976) identified pubescent voice change occurring at 12 years.

Although in the 21st century it is unlikely that anyone would advocate any technique to attempt to hinder or delay the natural process of maturation, the question of whether or not boys should sing through the transitional stage remains contentious leading Barlow and Howard (2002) to comment *"There are as many conflicting ideas on how child singers should be treated during this period as there are vocal pedagogues who deal with child singers."* Pabst (2000) calls for resolution of this problem without resorting to the re-introduction of castrati voices.

1.4 *The Research Area*

The complexity of the voice embracing physiological and psychological factors is compounded when it relates to children who are performing in what is often construed as a professional capacity, and who are also going into a crucial stage of physical maturation. A real understanding can only be achieved through a thorough exploration of all the interacting factors including non-singing activities, habits and behaviours and the psycho-social issues which are particularly pertinent for young boys who are also living away from their families. Equally important is an insight into the effect of voice maturation on impressionable youngsters and the impact this has when they are no longer considered able to perform, aside from any longer term effect on the vocal mechanism which remains unknown.

This study was instigated primarily to obtain information to assist the clinical management of choristers who were having difficulty with their singing voices, and from this to support the voice care of all adolescent choristers, particularly those in cathedral choirs. At that time it was not an area of research interest in the U.K., but has recently become increasingly popular.

Whilst aiming to obtain information on the most relevant features of voice production it is of necessity limited and focuses on describing qualitatively and quantitatively features of the voices of male adolescent choristers based on physical measurements obtained by ELG.

The impact of maturation on vocal function is one of the crucial factors for the children's performing voice and it would be useful to distinguish identification of vocal features related to growth and development rather than those which are the consequence of localised infection, vocal abuse, or other factors.

Comparison of assessments of those parameters which are most likely to indicate developmental changes, related to general measurements of growth could be expected to correlate with age related changes in vocal function.

ELG provides a non-invasive method of obtaining a physical measurement of a range of laryngeal features of the speech signal which can be related to perceptual judgements of voice quality. Because the technique identifies primarily vocal fold contact it provides an accurate basis for larynx frequency measurement which is not influenced by extraneous noise.

This study aims to contribute to the current knowledge of a most complex subject, focusing on the quantitative evaluation of aspects of vocal function using measures derived from ELG. The measures of Fo obtained from three sets of recordings made at yearly intervals are related to biometric measures and examined to identify characteristics and trends. Perceptual evaluation is based on a widely used rating scale (GRBAS).

The results obtained from statistical analyses are reviewed in relation to the key areas identified in the research questions.

- What are the quantifiable characteristics of changes in measures of Fo of male adolescent choristers, age 8–13years?

- Are these changes exclusively governed by physiological change or is there evidence of the influence of voice training?

- Are changes in vocal fold vibrational characteristics related to any of the measurements of weight and height?

- Can voice change associated with maturation be predicted from certain physical measures?

The study is presented in two sections. Part 1 contains pertinent background information; Part II describes the methodology and reports and discusses the results. Supporting data and related information is presented as appendices.

CHAPTER II THE LARYNX

2 *Introduction*

The primary function of the larynx is airway protection by preventing the ingress of saliva or foreign substances (food and drink) into the trachea. When particles threaten the airway a valving function closes the larynx, increasing subglottal pressure. When the vocal folds open suddenly in a cough any foreign body is expelled.

The larynx also functions as the sound generator which, as part of the vocal tract, is fundamental to speech production. The source-filter concept identifies the vibration of the vocal folds as the source of voiced sounds, and the vocal tract as the filter. The function of the larynx as part of the vocal mechanism is also related to protection and survival, from the hunger cries of the infant to screams of distress or warning. Integral to the acquisition of spoken language is the development of the co-ordination of the vocal mechanism to achieve controlled phonation, the most refined control being in singing.

Voice production is a dynamic process involving complex interactions and co-ordination, described by Husler and Rodd Marling (1976) as *"functional unity"*. The function of the larynx provides one element of this integrated process.
There are many sources of information on aspects of the structure and function of the larynx, (eg. Anatomy, Cunningham 2001; Aspects of muscle function, Greene and Mathieson 1990; Rubin 1998;. Structural misalignment, Caine 1998; the laryngeal frame, Zenker and Zenker 1960; Sonninen 1999; Atkinson 1978), therefore this chapter will focus on the relationship between growth of the larynx and vocal function.

2.1 *The Development of the Larynx*

Voice change related to maturation is not only a feature of puberty but a characteristic of all stages of life. Rapid growth from birth to two years of age involves neuromuscular maturation with increased articulatory agility and vocalisation with meaningful intonation and intensity. The descent and growth of the larynx results in a lowering of Fo which then stabilises until puberty. The notable features of the anatomical development of the larynx are (i) the descent from the level of the basiocciput (6th week of foetal life) to the level of cervical vertebra (CV) 1 at birth, and (ii) the realignment of the epiglottis.

LARYNGEAL DESCENT The larynx descends to the level of mid CV 5 by the age of 6 years, and at puberty descends to the level of CV 6.

Age (years	Tip of Epiglottis	Hyoid	Glottis	Inferior margin of Cricoid
0	mid C1	disc 2-3	mid C3	sup C4
6mnths	mid C2	mid C3	disc 3-4	mid C4
1	disc 2-3	inf C3	mid C4	disc 4-5
2	mid C3	disc 3-4	mid C4	mid C5
3	mid C3	disc 3-4	disc 4-5	mid C5
4	mid C3	disc 3-4	disc 4-5	mid C5
6	mid C3	disc 3-4	disc 4-5	mid C5
8	mid C3	disc 3-4	disc 4-5	mid C5
10	inf. C3	sup C4	disc 4-5	mid C5
Adult	inf. C3	sup C4	mid C5	disc 6-7

Table 1 The position of the laryngeal structures in relation to the cervical vertebrae and intervertebral discs. (From:The Position of the Larynx in Children and its Relationship to the Ease of Intubation. Westhorpe. (1987))

Although the relationship of the larynx to the cervical spine is influenced by postural changes these measures were derived from patients in a supine position with their heads in a neutral position .(Westhorpe,1987) and are consistent with the findings of Sasaki et al (1977). Arvedson and Lefton-Greif (1998) cite Wind (1970) in describing the lower border of the cricoid cartilage at the level of CV 6 by age 5years and at CV 7 by age 15–20years, continuing to lower slightly with age. Diagrammatic representation of the relationship of the laryngeal structures to the cervical vertebrae demonstrates that the lowering of the upper structures is marginal and the lower position of the inferior margin of the cricoid results from growth.

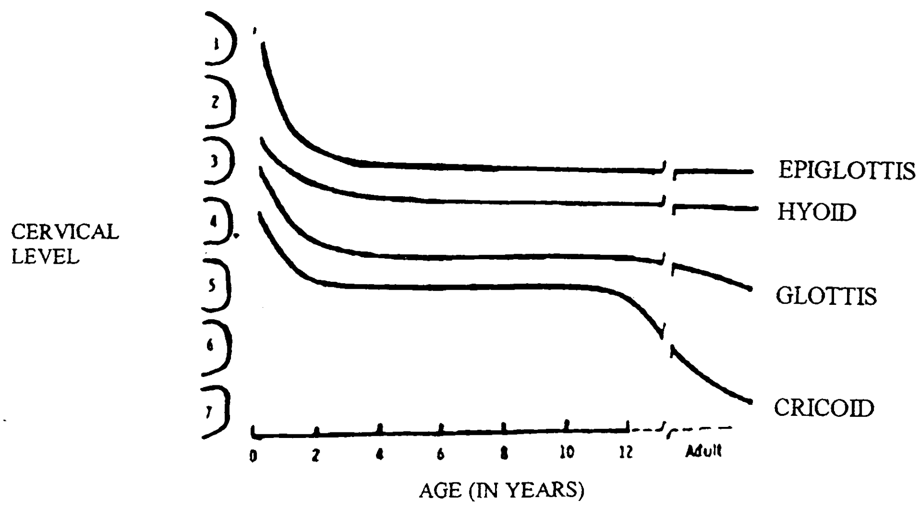


Diagram 1 The relationship of the laryngeal structures to the cervical spine. (Westhorpe 1987).

THE EPIGLOTTIS Sasaki et al (1977) report that although the function of the epiglottis in man has been disputed, in early infancy its role in separating the upper respiratory tract from the digestive tract is highly pertinent. The approximation of the epiglottis to the soft palate maintains an open airway from the nose, through the larynx to the trachea. The larynx of the neonate tilts downwards so the epiglottis is closer to the glottis, and the angle between the glottis and the tongue is more acute in infancy.

The descent of the epiglottis occurs at 4–6 months (although palatal-epiglottic approximation may exist up to four years of age, (Sasaki et al, 1977)) results in a functional change to nasal and oral tidal respiration, (the incidence of sudden infant death syndrome is highest for children age 3– 5 months). The epiglottis in the infant is not so rigid and although broad at the base the free edges are folded longitudinally; this fold can be well defined – described as an exaggerated infantile epiglottis. The infantile epiglottis is relatively longer and more tubular than in childhood when it becomes stiffened by chondrification and the fold opens to become omega-shaped. It retains this shape until enlarging and assuming the adult shape at puberty.
The lumen of the larynx and trachea is small. At birth the antero-posterior length of the epiglottis is 7–9mm and the lateral width at full abduction 6mm.

TRACHEAL DIMENSIONS:

Birth: 4cms

7 years: 5.5cms

Adult: 9 -15cms

The child's airway is not only smaller but proportionally smaller in relation to overall body size. The cartilaginous support is not so firm with a greater propensity to collapse, and the capacity of the mucosa to swell makes the effect of oedema more conspicuous.
At around 6 –8 years when there is a mid-growth /mid-childhood spurt which is comparable in girls and boys although it may occur approximately six months earlier in girls. Little is known about the mechanism of this growth spurt but it is thought to occur close to the initial rise in secretion of adrenal androgens. The second landmark occurs in adolescence (Preece 1992).

Kahane (1982) provides more detailed information on growth related changes to the laryngeal structure than was available from earlier, essentially descriptive studies. Measurements taken of prepubertal and pubertal cadaveric larynges were compared to available data on adult larynges, with reference to data reported by Maue (1971).

Developmental Stage	Chronological Age (Years)		Crown Heal Length (cms)	
	Mean	Range	Mean	Range
Prepubertal Male	10.8	9.7 -11.7	1.4	1.38 -1.47
Pubertal Male	15.1	13.0 - 18.7	1.71	1.60 - 1.82

Table 2. The increase in cms in the crown heel length of the larynx according to the developmental stage. (Kahane 1982)

The criteria used to determine maturation status for a male specimen was the presence of pubic and axillary hair as documented on the autopsy record, and for females a record of pubic hair and / or breast development.

The possibility of shrinkage resulting from preservation in formalin (cited Kahane 1978) or by freezing, (Maue 1971) was noted, and therefore specimens were dissected promptly and kept in physiologic solutions to minimise an effect on shape and / or size, enabling the researcher to be satisfied that cartilage measurements were not significantly altered by preservation. However, given the propensity of soft tissue to shrink because of dehydration it was acknowledged that measurements of laryngeal soft tissues may be underestimates, and that the measurements of vocal fold length may have been affected by such changes. No measurements were taken of the epiglottis because it had been excised or damaged under autopsy.

The findings of the study indicate that an increase in the size of the laryngeal cartilage results from appositional (external addition) and interstitial (internal expansion) with little change to shape. The most conspicuous feature was localised growth of the anterior aspect of the thyroid cartilage in males, with the intracartilage proportions of the arytenoid, cricoid and thyroid cartilages, which do not alter in shape significantly other than this antero-posterior dimension of the thyroid cartilage. Kahane (1982) reports that intracartilage proportions were noted to be relatively stable between prepuberty and adulthood for both males and females. The antero-posterior dimension demonstrated three times more growth in males than females, - 4.47mm compared to 15.04mm, and that this exceeded growth in cartilage width posterosuperiorly and inferiorly. The cricoid changes in males are therefore absolute growth and the intracartilage relationship of these dimensions relative to the overall growth in length, height and width of the thyroid and cricoid, which is two – three times greater in male than female.

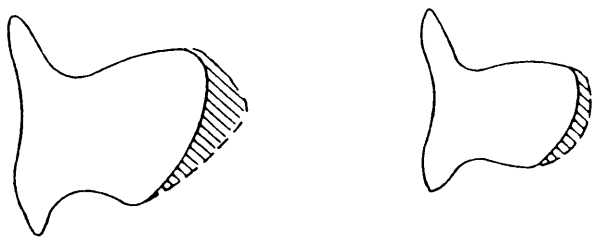


Diagram 2. The area of growth of the thyroid cartilage between puberty and adulthood. (Kahane 1982)

The angle of the alae of the thyroid cartilage changes from 110° at birth to 90° after puberty in males, whereas in females it remains constant at 120°.

The increase in size is reflected in an increase in the weight of the cartilage in males compared to that of females resulting from oppositional and interstitial growth and ongoing calcification or ossification of the cartilages which is important to the stability of the musculoskeletal laryngeal mechanism and therefore the efficiency of vocal function.

Cartilage		Total Increase Pre-pubertal to Adult (Grams)	Absolute increase pre-pubertal to pubertal		Absolute increase pubertal to adult	
			Grams	%	Grams	%
Thyroid	Male	6.35	2.95	46	3.4	54
	Female	2.17	0.82	38	1.35	62
Cricoid	Male	3.96	2.12	54	1.84	46
	Female	1.65	0.89	54	0.76	46
Arytenoid	Male	0.29	0.15	52	0.14	48
	Female	0.11	0.05	45	0.06	55

Table 3. Increase in weight of the laryngeal cartilages according to the developmental stage (Kahane 1982)

In reporting on this study Kahane (1982) referred to the implications of using small numbers of samples and advocated that inferences from the data should suggest trends and patterns of growth, not absolute growth; however, he also reported that growth patterns calculated from the data agree with that from an earlier study by Klock (1968) correlating growth in body height and postnatal laryngeal growth.

2.2 ***The structure and phonatory function of the vocal folds***

The acoustic output of the laryngeal mechanism is determined by the structure and vibratory behaviour of the vocal folds.

Typically the vocal folds are described as mucosal bands comprising five constituent elements in layers, homogenous along the membranous portion of the fold, although the thickness of the layer structure varies particularly at the extremities to protect them from the possible effect of collision during vibration. In a recent study of laryngeal closure pressure, measured as magnitude of pressure between the vocal processes at the end of phonation of the vowel [æ] at comfortable pitch for adult male subjects, Yamana and Kitajima (2000) reported pressure below 50cmH_2O. Laryngeal closure pressure was also found to correlate with pitch but notably not with intensity.

Hirano (1981) described a "body-cover" structure with the stiffer muscular body of the vocal folds and a soft sub-mucous cover. Histologically the layers are made up of muscle; three layers of connective tissue – lamina propria, (superficial, intermediate and deep) and the outer squamous cell epithelium – although the layers are not absolutely clearly delineated, except for the definition of the epithelium and lamina propria, and the superficial and intermediate layers of the lamina propria. The intermediate and deep layers of the lamina propria constitute the vocal ligament – the superior part of the conus elasticus.

The deep and intermediate layers of the lamina propria are not clearly defined. Notably collaginous fibres of the deep layer of the lamina propria infiltrate the vocalis muscle. Not only is the layer structure not distinct, (although defined histologically), neither is there consensus about the terminological definition, specifically regarding the lamina propria in relation to the vocal ligament.

What is critical is the dynamic properties of the folds, specifically in respect of the mass or variations of stiffness, which determine the vibratory capacity.

<u>THE VOCAL FOLD</u> is coated by an additional layer of mucus described by Hirano and Bless (1993) as a mucus blanket, which is essential to vibratory function. Hirano and Bless cite Hiroto (1966) that the vocal fold cannot vibrate if the fold surface is dry. The mucosal secretions emanate from glands superior, inferior, anterior and posterior to the edge of the membranous vocal fold, which in itself does not contain glands. Hydration of the larynx is considered important to vocal hygiene particularly for professional voice users, and clinicians, especially those working with professional voice users, will advise people to avoid drying elements such as alcohol and caffeine. Prior to the pilot study by Akhtar et al (1999) there was

no scientific evidence of the effect of caffeine on the vocal folds. These researchers acknowledge that with only eight subjects it can only be considered a small study which was not age or sex matched and demonstrated inter-subject variability; however, they noted an increase in irregularity of vocal fold vibration measured by ELG which was considered to support anecdotal evidence.

Insufficient hydration is considered to affect the production and viscosity of mucus with inadequate vocal fold lubrication. Globules of mucus clinging to the vocal folds can give rise to the vocal quality often described as 'a frog in the throat', and provoke throat clearing to alleviate the congestion.

A useful description of the layer structure is provided by Hirano and Bless (1993). These researchers emphasise the relevance of the structure to the mechanics of vocal fold function and identify the properties in three sections:-

a) The cover (epithelium and superficial layer of the lamina propria)

b) The transition (vocal ligament)

Passive control to these two layers is effected by the laryngeal muscles.

(c) The body (Thyrovocalis and Thyromuscularis); active control is effected by the muscle itself with passive control from other laryngeal muscles.

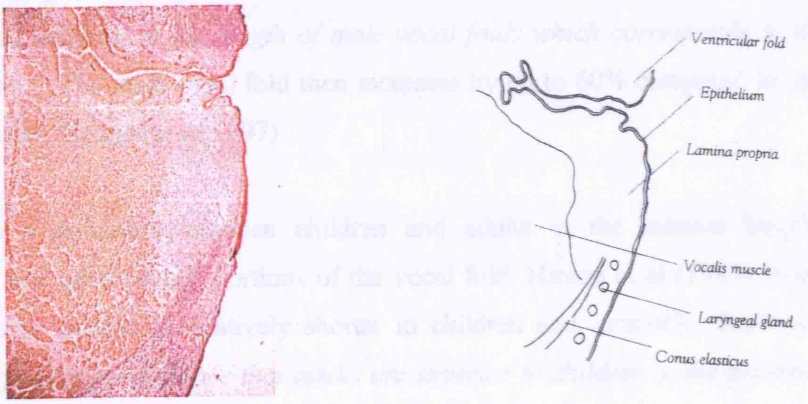
The result is "an elastic medium capable of absorption, transmission and reflection of acoustic energy." (Titze and Strong 1975).

Harris (1998) attributes the ability of the human species to produce a sustained phonatory tone, - unlike others - to the pattern of innervation. He cites Sanders (1995) description of the combination of "slow-twitch variety" of fibres nearest the ligament (the superior vocalis) graduating to the "fast-twitch variety" of the muscular portion. The configuration of the vibrating free edge of the fold is attributed to the construction of small bundles of fibres, which by varying the mass modifies pitch and register.

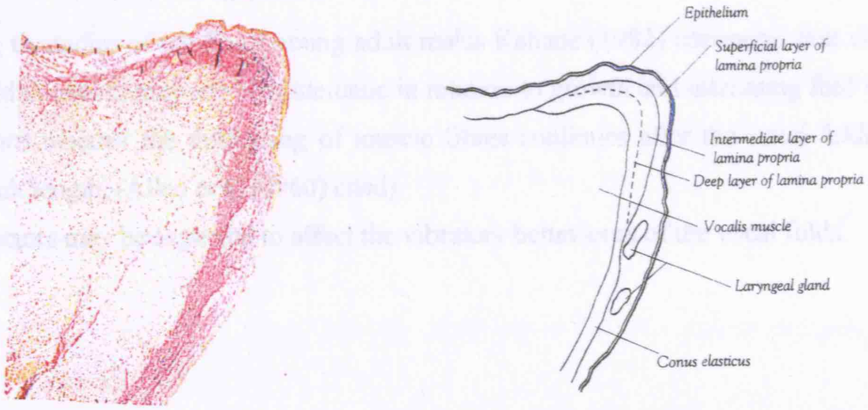
The significance of the combination of layers in generating complex mucosal waves is explained by Harris (1998) who describes the longitudinal tensing of the intermediate and deep layers of the lamina propria thinning the fold at the free border, with simultaneous firming, while the selective stiffening by the vocalis *determines* the configuration to effect various vocal timbres.

2.3 ***The development of the vocal fold***

The structure of the vocal fold changes as a function of age, and the development of the layer structure is not complete until the end of adolescence. Kahane (1982) cites the findings of the histological study of the vocal folds of Japanese cadaveric larynges at ages from birth to 80 years by Hirano et al (1981. Diagram 3), demonstrating that the vocal ligament is not histologically apparent before the age of four years, and that from 4–16 years collagenous and elastin fibres both increase in density and develop to form the deep layer of the lamina propria (vocal ligament); this development continues through puberty and is completed *"around the end of adolescence."* Hirano and Sato (1993).



NEWBORN



ADULT

Diagram 3 Coronal Section of the Vocal Fold: Hirano and Sato (1993)

Kahane (1982) reported difficulty measuring the length of the vocal ligaments because the consistency and colour of the vocal processes of the arytenoid cartilages could not be easily distinguished from the vocal ligament to establish the exact position. Hirano et al (1983) studied the length of the vocal fold as a function of age from larynges taken from autopsy cases; (newborn 2.5-3mm: adult 17-21mm (male); 11-15mm (female). Su et al (2002) identified vocal fold lengths of 14.6mm -15.2mm (male) and 11mm – 13.5mm (female).
Hirano et al (1983) reported that there is no difference between the male and female vocal fold length up to the age of 10years but the male vocal fold is longer from age 15years. These researchers did not have access to female larynges between the ages of 10-14years for comparison but deduced that the difference between the vocal fold length in males and females begins between the age of 10 – 14 years. These researchers comment that although this relates to the period of voice mutation *"there is no evidence from this investigation that there is a rapid increase in the length of male vocal folds which corresponds to this vocal mutation period."*. The male vocal fold then increases by up to 60% compared to up to 34% growth in females, (Spiegel et al.1997).

There is also a difference between children and adults in the relative length of the membraneous and cartilaginous portions of the vocal fold. Hirano et al (1983) reported that the membraneous portion is relatively shorter in children and, crucially, that this finding *"presents morphological evidence that adults are superior to children in the potential ability of voice control."*

In referring to studies of the Fo of young adult males Kahane (1982) comments that changes in vocal fold thickness may not be systematic in relation to growth and increasing fold length, and questions whether the thickening of muscle fibres continues after the vocal folds have attained adult length, (Allen et al (1960) cited).
All these factors may be expected to affect the vibratory behaviours of the vocal folds.

CHAPTER III VOICE PRODUCTION

3 *Introduction*

To establish the framework for this study, the energy source, sound source and sound modifiers required for speech production are discussed with reference to relevant studies.

Voice production involves an integration of processes which is more complex than the purely mechanical capacity of the larynx. The function of vocal fold vibration to produce voice was first identified by Ferrein in 1741 from experiments on animal larynges. The relationship of subglottal air pressure (Ps), vocal fold tension and Fo was identified in 1837 by Müller (Monsen et al 1978); Helmholtz in 1863 demonstrated the causal relationship of expired air at the glottis and phonation. Breathing behaviours are relevant to phonation. (Netsell et al (1994), Iwarrson et al, (1998); Thomasson and Sundberg (1999); Greene and Mathieson (2000)); likewise breathing patterns are affected by the vocal fold adduction and abduction, (Aronson, (1990), Greene and Mathieson (2000).

THE RESPIRATORY SYSTEM

The respiratory system is fundamental to life support; as well as being under automatic control it can be controlled voluntarily, particularly for speech, involving the complex integration of the metabolic, mechanical and behavioural aspects. Respiration is the process whereby oxygen reaches body tissues and carbon dioxide is eliminated. Tissue (or internal) respiration is use of oxygen by cells to generate energy; external respiration is the process of gas exchange between the atmosphere and the blood. The three stages of gas exchange are:- ventilation, perfusion and diffusion.

The stage to be considered in relation to phonation is ventilation, which is the process of air flow in and out of the respiratory system, comprising the upper respiratory tract, (the nasal and oral cavities, the pharynx, larynx and trachea), which acts as a filter to warm and moisten the air, and the lower respiratory tract, (the lower part of the trachea, the two primary bronchi and the lungs).

A review of the literature on breathing related to vocal function and speech identifies salient points pertinent to this study.

- The relationship between the mechanisms of breathing and phonation is not disputed.
- Differences in methodology used by researchers limit generalization and in certain instances the reliability of findings is questioned.

- Because of the number of variables influencing control of breathing at rest and during phonation findings are applicable only to the specific subject group, under the conditions specified and for the tasks undertaken.
- Information on control of breathing for speech cannot be extrapolated from studies of control of breath in response to metabolic changes.
- The anatomical and neurological differences between children and adults require separate studies of breathing function.
- Studies should take account of maturation, (including height and weight), respiratory health, psychological factors, and linguistic skills.

3.1 *The energy source*

The larynx and the respiratory mechanism are mechanically linked, (respiratory/laryngeal coupling), enabling the respiratory mechanism to exert the driving force on the larynx. (Hoit et al. 1993, Boliek 1997)); effectively functioning as the energy source for vocal fold vibration, (Holmberg et al.1988).

Changes in Fo are achieved by adjustments to vocal fold length and tension and related to Ps. Baken and Orlikoff (2000) emulated changes in the laryngeal driving pressure that occur during consonant production in speech and found that the loss of driving pressure caused a drop in Fo at the rate of 2.93Hz/cm H_2O in men, and 3.59Hz/cm H_2O in women. These researchers found that although theoretically it should be possible to make compensatory laryngeal adjustments to maintain Fo stability, even professional singers could not effect "feedforward compensation" of the larynx for the predictable loss of transglottal pressure. Extrapolating the findings of their study they suggest that a singer producing below middle C (220Hz) would experience a transient "glitch" of almost four semitones when articulating a voiced fricative – i.e.for the duration of the fricative the pitch would drop from A to about F; however, singers and listeners are impervious to this change, one reason being that the consonants are not as loud as vowels.

Atkinson (1978) sought to clarify the exact effect of laryngeal and respiratory function on Fo by investigating the physiological variable of Ps and averaged electromyographic data from the sternohyoid, lateral cricoarytenoid, vocalis, cricothyroid and sternothyroid muscles, demonstrating that the role of different physiological factors in determining Fo differs according to the conditions and the nature of the Fo change involved, and also for the different ranges of Fo. (summarised in Table 4).

		Highest Correlation
Low Fo	80 - 100Hz	Subglottal pressure
Mid Fo range	100- 120Hz	Sternohyoid
High Fo range	Above 120Hz	Cricothyroid
		Lateral Cricoarytenoid

Table 4. Physiological influences correlating to Fo (taken from Atkinson 1978)

Variability of intensity of speech and singing is associated with the effect of variability of lung volume, and corresponding Ps on vocal fold adduction. Plant and Younger (2000) suggest that because of the complex interaction between Ps, Fo and vocal intensity, accurate measurement of the aerodynamic properties of the larynx requires simultaneous evaluation of all three variables.

Hirano ((1981), reported Ps between 5 – 10cmH_2O in normal adult speakers phonating at their habitual pitch; comparable values were reported by Holmberg et al, (1988), (4.4 – 9.6cm H_2O); and Baer (1975): - 5 – 10cm H_2O, cited by Monsen et al (1978).

Iwarrson et al (1998) found that a reduction in intensity (for a diminuendo task) was associated with decreasing Ps and lung volume, with a corresponding decreasing airflow. Whereas for increased intensity (crescendo) the airflow is both increased by the increasing Ps but decreased with the decreasing lung volume, resulting in more variability between airflow and intensity than is evident in diminuendo. This was also found by Holmberg et al (1988) who reported increasing Ps in both male and female adult speakers on soft to normal, and normal to loud phonations; however no simple relationship was demonstrated between pressure and loudness indicative of a complex relationship involving vocal fold adjustment.

3.1.1 *Voice Onset Time*

Voice onset time (VOT) refers to the delay following the release of articulatory closure occurring in plosives before the commencement of glottal pulsing. It is relevant because it represents *"a very complex and extremely important aspect of articulator-laryngeal co-ordination."* (Baken and Orlikoff, 2000). It has been widely investigated in relation to developmental, neuromotor and linguistic disorders in adults as well as in normal speakers of many languages.

Baken and Orlikoff (2000) explain that the mechanism for control of VOT is not clear, whether it is related to the drop in transglottal pressure resulting from the pressure created by an oral closure, or to abduction of the vocal folds. Studies of changes in VOT related to maturation indicate that the ability to delay voice onset for voiced-voiceless distinctions occurs after the age of six years, with precision becoming more adult-like by the age of seven-eight years or even later, (Kewley-Port and Preston (1974); Zlatin and Koenigsknecht (1976); Eguchi and Hirsh (1969) cited by Baken and Orlikoff (2000)).

3.1.2 *The relationship between breathing and linguistic abilities*

The timing and extent of air replenishment is usually determined by sentence structure and punctuation of texts. Typical behaviours have been identified regarding inspiration in relation to structural boundaries in spontaneous speech, and sentence boundary of a paragraph in reading. (Winkworth et al (1994)).

Adams and Munro (1973, cited by Winkworth et al) demonstrated that where pauses are taken indiscriminately, the sense of the utterance is lost, and concluded that *"The amount of air breathed in and the amount of air in the lungs have been shown here to be strongly influenced by the length and loudness of the intended utterance, whereas the expiratory duration is largely determined by the linguistic intent;... "*

However, Horii and Cooke (1978) did not find consistent evidence in their subjects to support the premise that the anticipated utterance length governs the inspiratory volume and concluded that *"there are wide individual differences in respiratory strategy during oral reading; that typically, oral reading is done well within a respiratory capability (near equilibrium) and does not usually require special modification of respiratory manoeuvres that are dependent on the length of subsequent utterance."*

Monsen et al (1978) demonstrated that both Ps and vocal fold tension are instrumental in effecting changes of Fo but one or other is dominant according to the linguistic context. They found the influence of Ps was evident for stressed syllables and for frequency changes within syllables, leading to the conclusion that *"one cannot simply inquire into the means of lowering versus raising fundamental frequency: there appear to be different means of raising and lowering Fo depending on the linguistic intent."*

Less air is expired for each breath in reading than in spontaneous speech, (Hodge and Putnam Rochet (1989), cited by Iwarrson and Sundberg (1999). Horii and Cooke (1978) investigated inspiratory and expiratory airflow, volume, and duration characteristics in reading by adult subjects and found the time used for inspiration was approximately 13% of the speaking time, and that the average inspired volume was about 12% greater than the tidal volume. These behaviours indicate that the association between variability of lung volume during speech, and context, found from studies of adult subjects is significant.

3.1.3 *The relationship between breathing and psychological factors*

Breathing is both reflexive and under voluntary control and therefore susceptible to both operant and Pavlovian conditioning.(Ley 1994). It is associated with emotion, such as the erratic breathing pattern that accompanies crying and laughing, (Naifeh (1994), Winkworth et al (1995)).

Ley (1994) suggests that there is a reciprocal relationship between emotions and breathing; similarly Weiss (1994) refers to the interaction between the physiology of emotion, thoughts or action and the physiology of asthma.

Much of the work relating to breathing and emotion / psychological factors is based on specific disorders or events, (hyperventilation, trauma (such as bereavement) or situations which give rise to anxiety - such as the experience of children having dental treatment).

- Hollaender and Florin (1983) studied facial expression of emotion in children (aged 9–11years) with asthma compared to a control group in *"stress inducing competitive achievement situations"* and concluded that there is a relationship between emotion as demonstrated by facial expression and breathing.
- Winkworth et al (1995) reported that the speech topics used in a study to investigate breathing patterns during spontaneous speech were void of extreme emotion, and that any episodes of laughter were omitted in analysis of lung volume measures, arguably reducing the element of spontaneity and therefore the application of the data to spontaneous speech
- Denot-Ledunois et al (1998) investigated whether breathing was stimulated by excitement or suppressed by concentration and reported an increase in breath duration (from 2.56s to 3.16s) considered to demonstrate that concentration on a video game resulted in an inhibition of breathing.
- Van den Wittenboer et al (2003) investigated 'psychological well-being' in schoolchildren and respiratory variability and found a positive relationship between respiration rate and fear of failure.

These factors are all pertinent to this subject group.

3.2 *Speech breathing in children*

The complex interactions of the metabolic, mechanical and behavioural factors underpinning breathing demand further scrutiny when applied to children because of the effect of age / size related differences.

The rates and pattern of growth of the oral and pharyngeal structures differ with an accelerated growth rate during early childhood, until the development to adult size is complete by age 18years; (Vorperian et al. 2005). Development of lung size and capacity is linear to the age of 16years in boys, (13-14years in girls), whereas changes in the static recoil of the lungs is not linear, (Stathopoulos and Sapienza (1993).

Netsell et al (1994) attributed reduction in laryngeal airway resistance and increased flow to age-related increase in the size of the laryngeal airway.

Beckett et al (1971) suggest that the behaviours identified in maximal effort phonation in 7-year-old girls compared to boys may reflect different neuromuscular maturation and sex-cultural differences.

Stathopoulos (1986) comments that the intraoral pressure produced in children and adults speaking at the same intensity level is comparable, but higher in children asked to speak at "comfortable loudness", which may be related to smaller respiratory volumes, or may be associated with the social use of vocal intensity in conversation, (with reference to the finding of Susser (1980) that a child's 'comfortable' speaking intensity is on average 2dB more than used by adults).

Quantifiable differences in breathing behaviours can be related to size; however Stathopoulos and Sapienza (1993) found that the function of the child's laryngeal and respiratory systems (subjects age 4 years and 8 years) during speech, differs from the adults in relation to the *"amount of time the vocal folds were closed, the percentage of vital capacity used during speech, rib cage excursion range, and abdominal displacement at utterance termination".*

The rib cage excursion and percentage vital capacity were not explained but attributed to the greater compliance of the lung and chest wall.

Hoit et al (1990) studied quiet resting breathing and speech breathing in children at ages 7years, 10years, 13years and 16 years to identify the influence of sex and age and deduced that lung volume, rib cage volume and abdominal volume events in speech breathing change between the ages of 7years and 10years in advance of both maturation of the apparatus and acquisition of adult linguistic skills. Comparison of volume events of subjects age 10, 13, 16, and 25 years demonstrated similarities in speech breathing; speech breathing events related to syllable production were established by age 16years. The behaviours identified for spoken breath groups in spontaneous speech and reading were:-

- *"Initiated in the midrange of both the vital capacity and rib cage capacity and terminated in the lower portion of both the vital capacity and rib cage capacity.*
- *Initiated at relatively large abdominal volumes and terminated at slightly smaller abdominal volumes.*
- *Produced using primarily rib cage contribution to lung volume change."*

These researchers comment on the importance of considering speech fluency in evaluating speech breathing in children because of the effect on the number of syllables per breath group and the relative air expenditure per syllable. Similarly Russell and Stathopoulos (1988) reported that the number of syllables delivered by children per second was less than by adults, and was associated with more inspirations per minute.

Crucially in relation to the subject group of the present study Hoit et al (1990) state:- *"major changes in speech breathing take place prior to the onset of puberty, sometime between the ages of 7 and 10 years."*

3.3 *Breathing in singing*

Studies of breathing in singers are mostly based on adult classical singers, (Rothenberg et al, (1987); Watson et al (1989); Hirano et al (1989); Sundberg et al (1991); Thomasson and Sundberg (1999)).

Significant differences between singing and speaking relevant to breathing are that, (i) typically the singer can anticipate the breath support needs on the basis of knowing the length of utterance to be sung, and (ii) is unlikely to be interrupted, or to sustain an utterance to prevent being interrupted.

The control of the breathing pattern is considered fundamental to manipulate the singing voice by adjustments of the Ps (Leanderson et al 1987). Variations in loudness are achieved by varying Ps, and influenced by glottal adduction, Fo and formant frequency (Sundberg et al 1993). The difference between Ps in speech (conversational speech, typically lower than ~10cmH_2O: loud speech ~10-15cmH_2O) compared to singing (>40-50cmH_2O is significant. (Rothenberg et al.1987). However Sundberg et al (1993) point out that the vocal loudness and voice Fo are typically co-dependent, with the Fo raised as the Ps is raised, as well as other behaviours such as increased glottal adduction.

Pitch changes require an adjustment to Ps with higher Ps required to drive the stiffer vocal folds at high pitches than those at low pitches. The singer is therefore making constant adjustments to Ps according to the pitch and loudness; moreover these parameters must be controlled independently.

Sundberg et al (1993) investigated how the voice source in professional and non-professional male singers was affected by the variables of loudness, pitch and phonation mode, since singers are more able to control pitch and loudness separately. This demonstrated that vocal intensity is controlled by Ps but is influenced by other factors such as the inherent features of the vocal folds and the phonation mode. These researchers reported that *"in the entire material the authors did not find one single example of a singer who did not raise Ps when asked to raise vocal loudness."*; the average was recorded as a doubling of pressure per octave, and when the Fo was stable doubling of the pressure resulted in an average 10db increase in the acoustic pressure, (the term sound pressure level is used in most literature).

Unlike conversational speech the professional singer has to demonstrate replicability of his/her performance. Thomasson and Sundberg (1999) comment that erratic breathing and phonatory consistency are incompatible. These researchers investigated the consistency of phonatory breathing behaviours and rib cage and abdominal wall activity and found that singers use different strategies but inter-subject variation in the influence of rib cage and abdominal wall movements on lung volume changes precluded generalisation regarding breathing behaviours.

Underpinning performance is the control of the airflow. Rothenberg et al (1987) refers to the different mechanisms utilised to achieve this control.

- <u>Increasing the tension of adducted vocal folds</u>. This results in pressed voice quality and can adversely affect the laryngeal musculature.
- <u>The principle of inertive acoustic loading</u> (in male voices and the lower range of female voices). The air within the respiratory tract impedes the driving force of the expired air flow.
- <u>Formant tuning</u>. The technique of tuning the first formant to the voice Fo used by sopranos in the higher pitch ranges.

Crucially, Teachey et al (1991) found poor respiratory support as a principal feature of poor vocal technique in untrained professional singers and features of hyperfunction, (hard glottal attack, over-articulation, excessive loudness and throat clearing), and concluded that *"the untrained or minimally trained singer has a poor understanding of the capacities and limitations of the vocal mechanism."*

It is evident that breathing is multifactorial and therefore assessment and vocal training should take account of how all relevant factors interact, and specifically any strategies adopted by children and the implications of an immature apparatus.

3.4 The Sound Source

Holmberg et al (1988) commented that, *"The complicated interactions among aerodynamics, biomechanical, physiological and acoustic factors that characterise the glottal vibration pattern are far from being understood in detail"*, although subsequent developments in technology have enabled researchers to obtain information previously not accessible.

The key questions are:-

- What is the process?
- What is the control mechanism?
- What are the essential prerequisites?
- What is the effect of the variables?

posed at a more analytical level by Titze and Strong (1975):-

> *"What are the normal modes of vibrations of the vocal cords?*
> *Which modes are excited by the glottal air stream?*
> *What is the nature of the energy-loss mechanism within the vocal cord tissues?*
> *What is the effective mass of the cords for different vocal adjustments?"*

3.4.1 Vocal Fold Vibration

The present study centres on vocal fold vibratory behaviour, therefore it is relevant to consider the theories relating to vocal fold activity, and the vibratory cycle, with reference to relevant studies.

Evidence that cadaveric vocal folds can produce phonation from a subglottic airstream (Aronson 1980) is one of the arguments to refute the Neurochronaxic Theory mooted by Husson (1953) whose hypothesis was that the vocal folds are opened and closed by rhythmic contractions of the vocalis fibres of the thyroarytenoid muscle, (ie the neural firing) occurring at the same rate as the Fo.

The Neuromuscular Control Theory is based on the principle of mechanoreceptors located in (i) the mucosal lining of the larynx, (ii) the capsules of the articulatory joints and (iii) the extrinsic and intrinsic laryngeal muscles. It supports the concept of displacement of the vocal folds by the expired air stream, but attributes vocal fold return and adjustments of tonicity and movement to laryngeal activity initiated by the laryngeal mechanoreceptors. The presence of mechanoreceptors in the larynx is substantiated histologically; however, their function in relation to laryngeal activity is questioned (Kirchner 1983 cited by Greene and Mathieson 1997), although it is acknowledged that reflexogenic behaviour could account for features such as pitch fluctuations which occur without any apparent reason.

This may be relevant to uncontrolled pitch changes that characterise adolescent male voice maturation, attributed in part by Curry (1940, 1946), to reduced control of longitudinal tension of the vocal folds.

More widely accepted is the Myoelastic-Aerodynamic Theory first postulated by Mueller (1848) and developed by Van den Berg (1958), that the vocal folds are displaced from the position of adduction by aerodynamic-aerostatic forces and returned to the adducted position by myoelastic tissue forces.

The fundamental process involves rapid adduction of the vocal folds; the pressure of the exhaled air against the closed glottis (Ps) forces the vocal folds apart until the Ps drops. The minimum Ps required to produce sustained phonation is calculated at between 2 and 3 cmH2O (Lieberman, Knudson and Mead 1969, cited by Monsen et al 1978) with typical values for spontaneous speech of 5–10cm H_2O (Baer 1976). Holmberg et al (1988) reported glottal resistance values of around 40cmH_2O/l/s (range 12 – 93cm H_2O/l/s in adult subjects, male and female), consistent with values reported by Smitheran and Hixon (1981) of 30–40cm H_2O/l/s (syllable production at comfortable pitch and loudness). As the vocal folds are forced open the exhaled air is released; the constriction at the level of the glottis increases the velocity of the airflow at this points and therefore the pressure on the proximal structures is diminished, (the Bernoulli effect). The effect of the negative pressure in the glottis is that the vocal folds are sucked back together again, starting at the lower edge until complete closure is achieved. The initial medial movement is attributed to recoil.

The effect is twofold; the rapid drop in pressure above the vocal folds generates a pressure pulse excitation of the vocal tract, and inferiorly the Ps builds up until the folds are forced open again. For voice sounds the vibration of the vocal folds is effected by the combined force of the subglottal air parting them, and the effect of muscular, elastic and Bernoulli forces drawing them together, described by Titze and Strong (1975) as bilateral energy coupling between the glottal air stream and the vocal cord medium.

Howard (1998) attributes vocal fold opening to the inequity of supraglottal:subglottal pressure, with the greater force of the Ps forcing the folds open and what is described as the pendulum action of the folds with the momentum swinging the cords through the 'at rest' (equilibrium) position, to maximum opening before returning to the equilibrium position. The vibratory process is therefore cyclical with the natural frequency of the vocal fold action determining the cycle to cycle periodicity; asymmetry of movement (between the upper and lower portions of the vocal folds) in the vertical phase is one of the factors contributing to sustained oscillation (Titze 1976; 1980). The cycle by cycle periodicity was first demonstrated visually by Timcke et al (1958, 1959 cited by Aronson 1980) using frame by frame analysis of ultra highspeed photographs to show an open, closing and approximation phase for each cycle. This process should be regular and efficient.

3.4.2 *The opening and closing phases of the vibratory cycle*

Electroglottography (EGG) and (ELG) have demonstrated that vocal fold opening is more gradual than closing, although Rothenberg and Zalorian (1977) refer to high speed motion pictures of the vocal folds showing a tendency for faster opening than closing. Information about the degree of excursion appears to be limited. Rothenberg (1973) refers to area measurements of W.W.Fletcher reported by Flanagan (1958) of maximum separation of about 0.1cm averaged over the length of the vocal folds (adult subjects), and that the opening and closing in modal voice may take only 2msec. Titze (1980) reports maximum glottal width of 0.3cm in conversational speech.

Vocal fold closure is not uniform across the fold surface with contact occurring at the inferior border first, described by Childers et al (1986) as a "zipperlike" motion of increased contact from the inferior to superior margin, anterior to posterior to the point of maximum contact when the folds then part from inferior to superior margin, posterior to anterior to the point of maximum opening. Using vocal fold vibratory features extracted from ultra high speed laryngeal films they estimated vocal fold contact as a function of time and concluded that :-

- The vocal folds close and open in a 'zipper-like' manner.
- The opening and closing of the folds may differ from each other within a sequence of vibratory cycles.
- There is a phase lag between the movements of the upper and lower vocal fold margins.

Monsen and Engebretson (1977) attributed glottal source differences between male and female subjects to differences in the relative size of the vocal folds. The glottal wave of the male subjects indicated the out of phase movements between the upper and lower parts of the fold (consistent with the lag described by Childers et al 1986) whereas the female glottal wave was more symmetrical indicating closure of the shorter folds occurring more uniformly as a single mass.

Rothenberg (1981) identified the fact that glottal opening and closing is not abrupt over the length of the folds with contact and separation occurring sequentially over part of the fold length only.(Baer, Lofqvist and McGarr 1983). However; most pertinently, as reported by Holmberg et al (1988), representation of vocal fold movement differs according to the method used to study it, (Hillman and Weinberg 1981). Interpretation of waveforms of vocal fold vibration indicates differences in behaviour particularly in relation to intensity, (Monsen and Engebretson 1977). Anastopio and Karnell (1988) from a study of synchronised videostroboscopic and EGG examination of glottal opening reported glottal opening along the superior margin posterior to anterior, supporting the findings of Childers and Krishnamurthy (1985) from a comparison of EGG waveform and ultra high speed cinematography. However Anastapio and Karnell (1988) refer to the observations of Sonneson (1960) (superior margin opening anterior to posterior); Baer et al (1983) and Childers et al (1986), (middle to extremities).

Koike and Hirano (1973) observed a difference in the contours of the vocal folds (left and right) in a subject with normal voice. Significantly the vibratory period was uniform because of synchronised contact at the moment of closure, although slight differences in the timing of the peak of lateral excursion were discernible. The authors speculate that this discrepancy might occur in a pathological larynx but suggest that on the basis of the independence of the two folds (citing Moore 1968) it may not be uncommon in the normal larynx.

Koike and Hirano (1973) also observed the posterior chink during the closed phase from which it was construed that although the membranous part of the glottis was closed, glottal closure including the cartilaginous part was not complete. Gelfer and Bultemeyer (1990) observed less complete glottal closure at high frequencies in three of five subjects with more complete closure at low frequency but did not specify in what way, or at what point closure was deficient. Rothenberg (1973) also refers to incomplete closure posteriorly as "interarytenoidal leakage".

Both Rothenberg, and Koike and Hirano comment on the normal 'non-breathy' sounding voice, despite air escape during phonation. Sodersten and Lindestad (1990) associate complete fold closure as a feature of normal voice production but refer to variability of vocal fold closure in relation to normal chest register voice identified by early studies by Farnsworth (1940), Schoharl (1960) and Zemlin (1968).

Sodersten and Lindestad (1990) refer to studies identifying differences between males and females supported by their own study. These researchers used a rating protocol of glottal closure and identified an increase in incomplete closure and perceived breathiness in relation to decreased loudness.

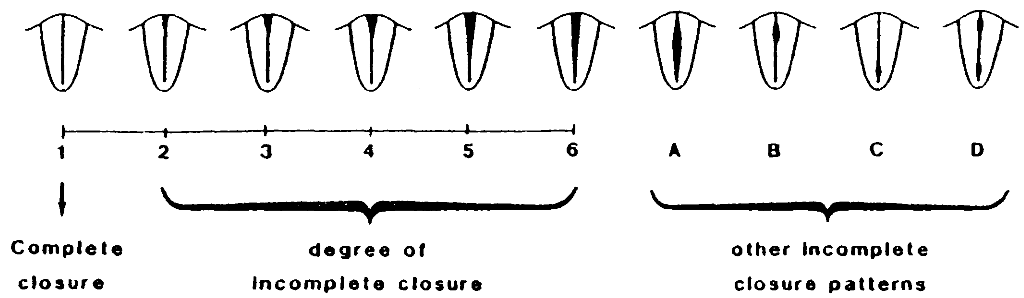


Diagram:4. Scalar points of the glottal closure during phonation.
From Sodersten and Lindested. (1990)

3.4.3 *Vocal Fold function in children*

The studies referred to relate to adult subjects and as White (1998) comments, knowledge of how the vocal function of children differs from that of adults is limited.

Sederholm (1996) reporting on a study of 10-year-old children concludes that *"a breathy voice and / or an incomplete glottal closure may be regarded as normal in 10 year old children."* From the evidence of experience in clinical practice a narrow posterior chink is not atypical but that it is a matter of degree of width – ie the difference between a chink and a gap, that determines whether this reduces vocal efficiency and introduces an inappropriate degree of breathiness into the vocal quality in relation to accepted ' normal' vocal quality and function and, furthermore, function in relation to age. Hirano (1974) questions the relationship between the maturation of the vocal ligament, temporo-spatial properties of vocal fold movement and vocal quality, and specifically breathiness, roughness or hoarseness, (Kahane 1982). It is also debatable to what extent vocal fold function should be related to the functional voice requirements of an individual. Incomplete closure may not obviously affect conversational voice use but significantly reduce efficiency in singing, and strategies applied to try to overcome this then lead to vocal strain.

3.5 *Vocal registers*

A complex subject relating to laryngeal adjustments and vocal tract resonance is vocal registers. Reference to the literature relating to vocal registers explains the statement by

Keidar et al (1987):-

"The pedagogical and experimental literature regarding the nature, number, names, definitions, boundaries, and essential features of vocal registers can be characterised as a collection of conflicting opinions that often lead to ambiguity and confusion. The number of register systems is almost as great as the number of authors who proposed them."

Baken and Orlikoff (2000) point out that there is no consensus on key questions relating to what a register is; whether it an acoustic attribute or a perceptual phenomenon; whether it is determined by laryngeal function or vocal tract characteristics, and how many registers there are. Notwithstanding this ambiguity the laryngeal adjustments associated with registers are pertinent to remediation of vocal dysfunction and in singing. Studies of registers focus on the adult voice.

The relationship between vocal registers and laryngeal adjustments was first described by Manuel Garcia, (1840), a singing teacher, renowned as the inventor of the laryngoscope, although Henrich (2006) points out that it had already been used by Babington in 1827 but Garcia was the first to use it successfully and defined register as *"a series of succeeding sounds of equal quality on a scale from low to high, produced by the application of the same mechanical principle, the nature of which differs basically from another series of succeeding sounds of equal quality, produced by another mechanical principle".* (cited by Large 1973).

Hirano et al (1970), reported register, pitch and intensity are inter-related with particular muscles dominant in the regulation of each of these parameters.

Whether vocal tract resonance is relevant (Titze 1988, Cleveland 1994), or not, (Hollien 1974; Sundberg and Kullberg 1999), is another area of debate.

3.5.1 *Perceptions of vocal registers*

Most studies relating to registers focus on production rather than perception, and are based on adult voice. Nadoleczny (1923 cited by Large,1973) expanded Garcia's definition to include reference to the perceptual skills of the listener, also discussed by Miller et al (2002). McGlone and Brown ((1969), cited by Baken and Orlikoff, 2000), found the ability of listeners to identify register transitions in speech unreliable, whereas a high level of agreement, (95.5%) between listeners (with and without experience) in identifying "experimentally classified" samples of modal and fry register was reported by Blomgren et al, (1998); Keider et al (1987) found high inter and intrajudge reliability in identifying chest and falsetto registers.

Large et al (1973), suggested the disagreement by experienced singing teachers with a subject's intended register may result from their loss of hearing acuity, particularly since register transitions are less conspicuous in soft phonation than in loud phonation.

Colton (1973) suggested that differences in acoustic pressure levels may be a factor influencing the perceived differences in loudness between heavy (chest) and light (falsetto) tones at the same pitch. A study of measures of acoustic pressure levels of phonations by singers and non-singers, at frequency levels within the region of overlap of modal and falsetto register at different vocal intensity levels, demonstrated little difference between the two registers at low intensity, but a significant difference at maximum intensity, and that typically the vocal intensities produced by the singers was greater than that of the non-singers, (Colton 1973). From this it was concluded that the range of acoustic pressures associated with modal register is greater than that associated with falsetto register, consistent with the findings of Katzenstein (1911), Sokolowsky (1912), and Large (1968), (cited by Large (1973)).

3.5.2 *Terminology for vocal registers*

It is generally accepted that there are three vocal registers identifiable in the speaking voice, determined by the vocal fold vibratory characteristics, (Sundberg and Hogset 2001), although Hirano et al (1970) refer to two groups – 'heavy' and 'light' registers; heavy includes chest, mid and head voice, and light relates to falsetto and 'light-head voice', and light-head is defined as "an intermediate voice between the head voice and falsetto in females.

Brief reference will be made to the terminology, appropriately described as *"an abundant vegetation of terms"* (Sundberg and Kullberg 1999).

The terms mostly used for speech in clinical and scientific papers are vocal fry, modal/chest, and falsetto. Hirano (1981, cited by Greene and Mathieson 2000) refer to loft, modal and pulse. (Titze (1988) comments on a *"whistle register"* identified as very high frequency vocal fold vibrations not warranting further discussion; previously Van den Berg (1968), cited by Keating and Buhr 1978), suggested 'whistle' register did not involve laryngeal vibration, Atkinson (1978) suggests that as well as the recognised registers, there are two Fo regions within chest register in the speaking voice related to different laryngeal states:-

State	Vocal Folds	Strap muscles	Primary Fo Control
Low Fo	short, thick, slack	Tense	Subglottal pressure
High Fo	long, thin, taut	Lax	Cricothyroid muscle

Table 5 Laryngeal states in Fo regions of chest register

Hollien (1974) sought to clarify the subject by defining registers in speech as a *"totally laryngeal unit"*, each comprising *"a series or range of consecutively phonated frequencies which can be produced with nearly identical vocal quality."*

Singers and singing teachers may use the terms chest, middle, and head, for women, and chest, head and falsetto, for men (Hill, Parfitt and Ash 1995), Husler and Rodd-Marling 1976), who also refer to a middle register (voix mixte); a register above the falsetto-head (flageolet); and a register below the chest (growl).

Although Hollien specified little or no overlap of Fos, this is another area of ambiguity. Lerman and Duffy (1970) refer to overlapping of the normal and falsetto range; Keidar, Hurtig and Titze (1987) found no overlap between fry and modal in 22 subjects able to produce vocal fry.

Titze (1988) suggests registers are classified according to the type of transition:-

(i) Periodicity – for which the acoustic variable is Fo, and

(ii) Timbre – with the variation in high frequency sound energy caused by changes in vocal fold closure resulting in abrupt changes in vocal quality.

The transition between registers is critical to singers.
Registers are related to Fo ranges although this is not the only feature, as shown by a small range of frequencies common to more than one register, (modal and falsetto), (Colton 1973). The key features of the registers are the perceptually *"distinct regions of vocal quality"* (Titze 1988), associated with Fo ranges and the characteristics of the vocal fold vibration.

3.5.3 *Pulse Register*

Van Riper and Irwin (1978) had identified this mode of phonation as the lowest at which an utterance can be sustained. Hollien and Michel (1968) investigated whether vocal fry (the term they used at that time), is a separate phonational register, or associated with modal register, and concluded that it is a low frequency vocal register.

They found little difference between the mean ranges of males and female adult subjects.

Source	Year	Fry Register Male	Female
Hollien and Michel	1968	24 - 52Hz	18 - 46Hz
McGlone	1967	10.9 - 51.0 Hz	15.5 - 48.8 Hz
Murry	1971	22 - 92 Hz	
McGlone and Shipp	1971	18 - 65 Hz	
Blomgren et al	1998	49.14 Hz	48.1 Hz
Literature Average		20 - 70 Hz (Mean 50 Hz)	

Table 6. Fo in Fry Register (previous studies)

The perceptual characteristic of pulse register is a creaky, grating quality, with a monotony resulting from the typically narrow Fo range. The physiological features of pulse register are:-

- shorter vocal folds
- short opening and closing phase with a long closed phase; Hirano et al (1970) attributed the long closure phase and thick vocal folds in chest register mainly to the contraction of the vocalis, assisted by the lateral cricoarytenoid and the interarytenoid and that the activity of these muscles is related to pitch in the 'heavy' register.
- the activity of the thyroarytenoid muscle is relatively unopposed. (Allen and Hollien 1973).
- low air flow rate, attributed to the long closed phase (10-100ml/s, compared to the rate in modal register of 70 –180ml/s), (Murry et al (1971) cited by Blomgren et al (1998).
- greater Ps values, (8.0–11.0 cmH2O compared to 5.0 – 6.0 cmH$_2$O in modal register), (Murry 1971), however this has not been supported by other studies, (McGlone and Shipp, 1971; source Blomgren et al, (1998), and these researchers' own findings), although they questioned whether the different findings resulted from different measurement procedures.

Other features found by researchers reported by Blomgren et al (1998) are:-

- smaller glottal pulse widths (Childer and Lee, 1991),
- double opening and closing of the vocal folds in rapid succession, (Moore and Von Leden 1958) - although this was disputed by Hollien et al (1977), Whitehead et al (1984) reported double or triple opening and closing activity before a long closed phase; this is supported by the results of EGG analysis by Blomgren et al (1998), which demonstrated either single open and closed phase, or multiple (doublet and triplet cycles) within a single vibratory cycle. The researchers suggest this pattern may result from oscillations per cycle on the free margin of the vocal fold and cite Zemlin's finding (1988) that the vocal folds *"approximated tightly, but at the same time they appear flaccid along their free borders, and subglottal air simply bubbles up between them at about the junction of the anterior two-thirds of the glottis."*

Characteristics of the vibratory cycle are the thickening of the vocal folds, with reduced stiffness of the vocal ligament which reduces the rate of the vocal fold vibration, (Blomgren et al. 1998), although Allen and Hollien (1973) found no evidence of a correlation between the thickness of the vocal folds and Fo in pulse register; the vocal fold mass used by females was less than observed in males. A notable finding of this study was that the action of the ventricular folds significantly reduced the ventricular space supporting Hollien's suggestion (1966) of associated ventricular fold adduction.

Pulse register is therefore identified as a low frequency register within the normal pitch range, (Keider, Hurtig and Titze, (1987)), typically occurring at the end of falling Fo, as the pitch and intensity tails off. This may be associated with breath support behaviour – although Blomgren et al (1998) suggest Ps may be reduced actively to achieve the low Fo, it may be the consequence of an inability to sustain sufficient expired airflow to support the voice. Despite the harsh quality it is not classified as a vocal pathology (Hollien and Wendahl (1968), cited by Blomgren et al (1998)), and can be a conspicuous feature of some cultures; however excessive occurrence of this mode may be indicative of vocal dysfunction.

3.5.4 *Modal Register*

Modal register is related to the Fo range most typically used in the 'normal mode', although the upper frequencies may also feature in the falsetto register. Modal register shows the most significant gender differences.

Keidar, Hurtig and Titze (1987) reported a group range of 71–516 Hz (34.3 semitones) with 50% of the subjects showing no overlap between modal and falsetto, and some subjects unable to phonate between these two registers.

There is a distinctive mode of vocal fold vibration, with the vocal folds adducting firmly along the anterior margin,and a posterior glottal chink - although this is another area of ambiguity since a glottal chink can be found in both normal and pathological voice. Sodersten and Lindestad (1990) reported incomplete posterior glottal closure as a feature in women, and complete closure in men. Murry, Xu and Woodson (1998) reported that incomplete glottal closure should be regarded as normal for high frequency phonation in both modal and falsetto register. These researchers also reported finding both hourglass and spindle glottal configuration in normal subjects in both modal and falsetto register.

The higher Fos in modal register are effected by contraction of the vocalis muscle increasing the longitudinal tension, (Laver 1980). An investigation of the activity of the intrinsic laryngeal muscles in singing, by Hirano et al (1970), using electromyography found the activity of the vocalis muscles essential to register regulation.

Titze (1994, cited by Sundberg and Kullberg, 1999), describes the lower margin closing earlier than the upper margin with a more gradual opening from the inferior border upwards, posteriorly to anteriorly, increasing in rate as the Fo rises. The vertical phase difference with the delayed opening of the upper margins, prolongs the closed phase.
This vibratory cycle is relatively regular depending on the Ps pushing the folds apart and the combined muscular, elastic, and Bernoulli force drawing them together.

3.5.5 *Falsetto Register*

This register (also referred to as loft register) is perceptually related to the highest Fo. Although a small range of pitches at the low end of the falsetto range may also be produced at the upper end of the modal range, falsetto is not habitually used in speech being described by Lerman and Duffy (1970) as *"inefficient, ineffective, and generally unpleasant."*

Falsetto voice has also been associated with clinically abnormal voice (e.g. persistent high pitch voice in the post-pubescent male). Because the falsetto register is not used in normal speech, studies are based on singing tasks, and particularly the transitions from modal to falsetto and the reverse. It is distinct from a child's voice. Lerman and Duffy (1970) investigated the perceptual features of phonation (falsetto, normal, female and child), and reported that falsetto was not perceived as a child's voice. Damste and Lerman ((1969) cited by Lerman and Duffy (1970)) stated; *"falsetto voice is different from the child's voice and is characterized by its weak quality and small dynamic range. It is a sound that can only be produced by a sexually developed larynx."*

The falsetto register is produced by the dominant longitudinal tension in the vocal ligament resulting from contraction of the cricothyroid muscle; the small amplitude with a short closed phase limits the overtones (Van den Berg, (1960) cited by Hirano (1970)). The increase in pitch is not associated with lengthening of the vocal folds, (Hollien (1960), and Hollien and Moore (1960) cited by Hirano et al (1970).

3.5.6 *Vocal Registers in Singing*

"Registers should never be anything more than the sounds made by the activity of individual muscles temporarily dominant within the whole co-ordinate process. To work with 'registers' in the belief that one is dealing with separate entities, each one having an independent existence, is to run the danger of so disrupting the vocal organ that only fragments of it – 'registers' remain." (Husler and Rodd-Marling, (1976).

Adults master different styles of singing, and apply different techniques to achieve the desired quality, (Sonninen et al 1999). Whatever the style, registers, and the transition between registers (passaggio), are important. Hill et al (1995) refers boys being required to produce chest voice, with difficulties misinterpreted as the voice 'breaking', and incorrect training of ascending scales and exercises resulting in breaks between middle and head voice. Miller et al (2002) comment that *"smoothing and disguising register transitions is a widely acknowledged principal goal of singing instruction, and the degree of discontinuity between chest and falsetto voices that must cross this primary register transition in practice can hardly be irrelevant".*

Sundberg and Kullberg (1999) suggest that differences in glottal adduction between registers among subjects may reflect behaviours used to conceal register transitions. Whereas the increased adduction may be effective when used by a trained singer, in less proficient singers, it may result in hyperfunction and lead to other difficulties.

Svec, Schutte and Miller (1999) examined abrupt transitions from chest to falsetto register and found that, in excised human larynges, an abrupt change of register can be caused by a small and gradual variation in vocal fold tension. This 'leap' is distinguished from a pitch change within a single register by the speed of transition, occurring with a few glottal cycles, whereas an increase in Fo is spread over a greater number of glottal cycles, (Miller et al 2002). Svec, Schutte and Miller (1999) found the 'leap interval' (the relationship of Fo in falsetto and chest registers in semitones,) in living subjects differed, and attributed these differences to the biomechanical properties of the vocal folds. A smooth chest-falsetto transition in the female was associated with a small leap interval.

Examination of the ratio of vocal fold contact in the vibratory cycle (closed quotient), demonstrated a reduction (particularly in male voices), over the last six cycles of chest register with only a slight rise in Fo, which it is suggested may result from a sudden loss of the deep vocal fold contact, resuming with vibration of the upper margins, and higher Fo; there may be a brief period of instability (Miller et al 2002).

Other sung intervals identified by these researchers were transitions combining leaps and gradual transitions, and leaps with tuned vocal tract resonance, as in yodelling.

The results of a radiographic study of laryngo-pharyngeal positions and relationships during singing by Sonninen et al (1999) identified the way in which the inter-relationship of the laryngeal structures changed according to pitch and singing mode. Although the authors caution against both generalising the findings derived from one singer, and interpreting the measurements in isolation, their opinion that *"laryngeal distances (and the muscles involved) should be considered as links in a chain, a mandible-hyoid-thyroid-arytenoid-cricoid-cervical spine (MHTACC) functional chain."*, echoes the concept of 'functional unity' promoted by Husler and Rodd-Marling (1976).
Sonninen et al (1992) suggest that the abrupt decrease observed in the spatial relationship of the thyroid and arytenoid cartilages immediately below the passaggio *"can be interpreted as indicating a trade-off in the function of the muscles."*

3.5.7 *Vocal Registers in Children*

Although there is a growing interest in child voice and voice therapy for children, the number of studies of child voice remains relatively small. McAllister et al (2000), suggest registers in children's voices differ from those of adult voices. From a study of perceptual identification of register transition and their relationship to Voice Range Profiles (VRP)[1], in ten-year-old children, register transitions were identified in fourteen of fifteen voices at 472Hz mean Fo, but was found at a lower Fo in soft phonation compared to loud phonation, (consistent with the findings of Sundberg and Kullberg, (1999) in adults. A

[1] A voice profile (phonetogram) derived from measurement of frequency combined with intensity.

second transition was noted in the controls at mean Fo 807Hz, and in mutational voices at 1003Hz.

Flatau (1905), cited by McAllister et al (2000) reported a register transition at around 1048Hz in some voices of pubertal girls, - described as changing into *"a fourth register with a wood instrument like timbre."*, and Pabst (2000) refers to register break regions identified in phonetograms of boys aged 8years – 15years.

Adolescent voice has been extensively studied by Pedersen and co-researchers using phonetograms. These studies mostly focus on the lowering Fo in relation to maturation. Register shifts were identified by perceptual evaluation compared with calculations of the middle of the narrowest part of the phonetogram, for three choristers (Grade 7), and demonstrated a reduction of the *"intensity variation capability especially at the register shifts."*(1993), The ongoing changes in vocal function associated with the natural process of maturation, and the pitch breaks that occur as part of that process, complicate distinguishing registers and register transitions.

The problem of ambiguity around this subject with differing views regarding definition, scope and terminology; is compounded by the relevance of registers to both scientific and artistic disciplines.

3.6 ***The Sound Modifiers***

The sound generated from the sound source is modified by the vocal tract; the pharyngeal and oral cavities and the articulators.

- Xue et al (1999) studied the acoustic effects resulting from enlargements in the pharyngeal configurations and articulatory modifications in older speakers and considered age-related changes in the vocal tract dimensions to be more complicated than increases in vocal tract length.
- Several other researchers refer to the effect of articulatory placement on the intralaryngeal behaviours, (Zenker and Zenker (1960), Linville (1988), Ohala and Eukel (1977), Honda (1983)).
- Ohde (1985) examined the effects of tongue height on intrinsic Fo in the speech production of children and reported higher Fo for vowels /i/ and /u/ with high tongue positions, than for /a/ with a low tongue position. Similarly the intrinsic Fo ratios between labials, alveolars and velars were found to be lower for labials than alveolars and velars indicating that the consonantal anchoring with high tongue tip

or body placements and a high tongue vowel placement produced a relatively higher Fo in childrens speech.

Nittrouer et al.(1990) commenting on the inadequacy of studies of the coarticulation of laryngeal gestures with supralaryngeal gestures using acoustic measures, recommend that such information on normal adult speakers is required before it is investigated in children as otherwise typical patterns of such coarticulation would not be known, but also suggest that measurement of the acoustic consequences of laryngeal/ supralaryngeal coarticulation is inadequate without knowing the laryngeal activity specified by each acoustic measure.

CHAPTER IV VOICE FUNDAMENTAL FREQUENCY

4. *Introduction*

Because of the demands placed upon the choristers, with the emotional and psychological implications of voice change, often occurring when they are musically at the peak of their career, any indicator of voice change would arguably enable problems and the transition to the adult voice to be sensitively managed. Voice mean Fo is not a parameter for prediction of voice mutation, (Fuchs et al. 1999); however, voice, and notably the Fo, which relates to perceived pitch, of voice is recognised as conveying information about an individual's age, gender and sex. (Bennett and Weinberg 1979; Debruyne and Decoster 1999, Murry and Singh 1980)

The Fo of voice is determined by the mass and vibratory behaviour of the vocal folds and the aerodynamics of airflow through the glottis. The voice change of the adolescent male results from laryngeal growth under hormonal influence, specifically in relation to vocal fold length, and is characterised by the lowering of the fundamental pitch, (Ohde 1985).

Perceptual gender differences arise from the decrease in Fo of boys from age 7 years, (Crelin 1973, cited by Hasek et al; Sorensen 1989), co-inciding with the growth spurt resulting from hormonal interaction at about 6-8 years.(Preece 1992). Sorensen (1989) suggests that male Fo lowers in the age range 6–7 years then stabilises from 7–10 years.

Fo is dynamic and this chapter describes the normal variations, and some of the factors which influence voice use and potentially pitch with reference to relevant studies.

4.1 *Habitual pitch*

Habitual pitch is the narrow range of pitches which are used most consistently and correlate to the individual's average (modal) speaking Fo, defined by Case (1996, cited by Zraick et al 2000) as:- *"the modal or average pitch heard in a continuing sample of speech, the level around which normal pitch inflections occur."* This pitch should be age and gender appropriate; when it does not conform to the norm it challenges the listeners constructs, (Barbier 1989)

The term 'habitual' implies relative stability of Fo characteristics, (Coleman and Markham (1991)); however speaking behaviours vary, with associated variations in vocal characteristics according to the situation.

Coleman and Markham, from a study of adults, found them to be within 3 semitones (S/T) of their average speaking Fo at least 90% of the time although intraspeaker variations of as much as 18% from day to day may still be within normal limits.

4.1.1 ***Fundamental Frequency Range in children***

Phonatory frequency range is the range of Fos, from the lowest sustainable tone in modal register, to the highest tone in the falsetto register, (Hollien et al (1971)). This definition includes modal and falsetto but excludes vocal fry. The physiological range is the range of frequencies it is possible to achieve; the speaking Fo range is the range the speaker uses, (a further dimension is the singing range).

The speaking Fo range is a useful indicator of vocal behaviour and potential dysfunction. Wendler and Anders (1986, cited by McAllister et al 2000) identified a restricted range in children (less than 18 S/T) as a useful measure to identify dysphonia. McAllister et al, however, report that whereas Bonet and Casan (1994) found a high correlation between this measure and perceptual and laryngeal evaluations, in her own study of the 7 children age 10–15 years with voices described as ' deviant' only two had a pitch range of less than 18 S/T.

4.1.2 ***Normal Pitch Variation***

Factors which influence pitch include:-

- Language specific use.
- Vocal Behaviours – pitch variations appropriate to the style required for a particular situation / audience or reflecting mood.
- The *"unique speaker specific aspects of the voice signal"* (Murry and Singh. 1980) - attributed to anatomical differences in the vocal structure and learned differences in the use of the vocal mechanism.
- Intraspeaker variations –variations occur for the same task under the same circumstances, (Coleman and Markham (1991) caution researchers *"in interpreting statistically significant differences of less than 10-15% within individuals or between treatment groups."* Because of intrasubject variability.
- Vocal fold dysfunction or pathology, (Van Oordt and Drost, (1963); Murry and Singh (1980))

4.1.3 *Variability in Childrens' Speaking Voices*

Because of the significant differences in structure and function between the larynges of adults and children, it is not appropriate to apply data from adult subjects to children, (Helyen et al (1998)).

Pitch variability in young childrens' speech may be related to the immature neuromuscular system resulting in more temporal variability. (Kent and Forner 1980, cited by Robb, Saxman and Grant (1989); Smith et al 1983 cited by Ohde 1985). This is questioned by Whiteside and Hodgson (1999) with reference to the finding of Eguchi and Hirsh ((1969) of age-related decreases in intra-subject standard deviations to a minimum of 12Hz by age 10–12 years attributed to increased precision of motor control over a 7– 8 year period, (realistically 12Hz, is minimal; e.g. 225Hz – 237Hz is a difference of only 0.89 semitones). Ohde (1985) relates greater variability in Fo in children age 8 – 9 years to the immature speech mechanism with adultlike neuromuscular control not occurring until the age of about twelve years, (cited Tingley and Allen 1975).

Bennett (1983) cites Kent (1976) suggesting that changes in Fo maturation considered age-related, may actually be reflecting variability in children's vocalisations; this should be taken into account when making age-related comparisons of Fo. Bennett (1983) collated data from four other investigators with her own to show that it is difficult to characterise the *"typical"* Fo of a child an any given age, based on differences of up to 60Hz in the mean or median values reported for speakers of the same age.

Kent (1976) commented on the possibility that *"age-related differences in mean Fo are caused as much by variations in the vocalization activities as by anatomical and physiological maturation."* whereas Hollien et al (1994) report that the onset of adolescent voice change *"could be identified as the SFF peak which was preceded by a generally varying Fo pattern for a period of at least four months and succeeded by a decreasing SFF slope at a minimum rate of one semitone(st) per month for at least six months."*

This would provide a useful and easy system of monitoring if vocal behaviour and fluctuations resulting from variations in voice use could be distinguished.

4.1.4 *Voice Breaks as a feature of voice maturation*

Voice breaks - sudden, brief, uncontrolled and unpredictable interruptions to the pitch outside normal more gradual pitch variability - are usually regarded as a typical phenomenon of male adolescence associated with voice maturation

However voice breaks similar to pre-adolescent controls were found in a group of ten year olds (Curry 1940), and in seven- and eight- year-olds, (Fairbanks, Wiley and Lassman 1949). Fairbanks, Wiley and Lassman (1949) compared the vocal pitch characteristics of boys aged seven years and eight years and found voice breaks as a feature of both groups - estimated to have occurred once every 14 words in a 52 word passage. These were reported to be comparable to those of older boys which they considered to indicate that voice breaks are not an exclusive phenomenon of adolescence.

Fairbanks, Herbert and Hammond (1949) undertook a study of girls age seven years and eight years to test the hypothesis that voice breaks are not in fact gender specific, and found the occurrence of non obtrusive voice breaks, which were not attributed to the apparatus or procedure, and, concluding that voice breaks are a non-sex-linked phenomenon of childhood, questioned why – since Aristotle's time – they have been observed during and associated exclusively with male adolescence.

A possible reason suggested is the relationship of the voice breaks to the average Fo as reported by Fairbanks, Wiley and Lassman (1949). Voice breaks occurring in the lower part of the pitch range may be unremarkable as a feature of childhood. However, as the male pitch lowers the voice breaks occur above, rather than below the average Fo, rendering them more conspicuous compared to the predominating low, quasi-adult pitch.

4.2. *Fundamental Frequency and perceptions of speaker sex in children*

The main cue to distinguish speaker sex is Fo and the perceptual correlate of pitch. (Coleman (1971. 1976) cited by Gunzburger et al (1987).

- Weinberg and Bennett (1971) tested the hypothesis that average voice Fo influences the listener judgements of the speaker's sex, with specific reference to pre-pubertal children (5 and 6 years old) for whom the mean voice Fo is comparable. These researchers reported a 74% correct identification of a 30 second sample of recorded speech and concluded that this was not accounted for by the average voice Fo characteristics, and subsequently demonstrated that laryngeal source cues played a relatively minor role in the process of sex recognition, (1979). They refer to studies demonstrating that the sex of some children can be identified from speech recordings – (Weinberg and Bennett 1971; Marshall 1972; Ingrisano and Thompson 1975; Sachs et al 1973; Sachs 1975); but observe that the acoustic features which influence these judgements are not specified. However, they suggest the features of mean Fo, Fo range, syllable rate and relative amplitude are not critically relevant and that perceptual judgments may be influenced by intonation patterns. (Ingrisano and Thompson (1975) and Sachs (1975) cited).

- Bennett and Weinberg subsequently (1979) examined perceptual judgments of average Fo, variations in Fo related to intonation and vocal tract resonance characteristics, of voices of pre-adolescent children, (73 boys and girls aged six years and one month, to seven years and ten months), and found that a key variable which appeared to influence judgements was perceived monotonicity because of use of a narrow pitch range. Although intonation patterns overall did not convey primary information about sexual identity, monotonicity and decreased variations in Fo were more likely to be associated with male vocal quality. Bennett and Weinberg (1979) also suggest that formant frequency values reflect the anatomic differences in pharynx length between boys and girls prior to the onset of puberty (with reference to data from King 1952), and influence listener judgements of male or female voices.

- Murry and Singh (1980) explored the number and nature of perceptual parameters influencing judgement of voice similarity according to speaker sex and sample size and concluded that Fo was important for all judgements but the vocal tract parameters were more influential to judgements of maleness, and perceptual features of vocal quality and vocal effort were more influential to judgements of femaleness. However, they also found that listeners attended differentially to the vocal parameters when the sex of the speaker is known.

- Debruyne and Decoster (1999) who investigated the ability of listeners to distinguish voices as young or old from a segment of sustained vowel concluded that perceptual recognition of age is a multifactorial process.

- Gunzburger et al (1987) found that correct identification of prepubertal boys and girls was higher based on sentences than on isolated vowels and concluded that identification was influenced by the effect of articulation on spectral information. Where listeners were unsure they made a judgement on "sloppiness of articulation", the more 'sloppy' articulation being attributed to the boys. Judgements by blind listeners were that girls voices were significantly clear, soft, shrill, high pitched, melodious and precise compared to boys' voices which were considered significantly dull, loud, deep, low pitched, monotonous and careless. These researchers suggested that in the absence of sex-dependent anatomical differences in the vocal apparatus differential speaking habits must take root before puberty. The subjects of their study were selected from a primary school so it may be assumed they were matched in terms of regional and social accent.

4.3 *Factors influencing the use of fundamental frequency*

The vibratory capacity of the vocal folds may be adversely affected by dehydration, and aggravants such as cigarettes and drugs. The way in which an individual uses vocal pitch may be related to emotional and cultural issues. These are discussed further.

4.3.1 The effect of hydration on fundamental frequency

Voice care is essential to anyone using their voice in a professional capacity and is particularly relevant to children who cannot control their environment, and who typically shout when playing games etc.

Advice on voice care from clinicians and voice coaches alike, usually includes a recommendation to "drink a lot of water", avoid dehydrating agents and maintain relative humidity in the environment. (Richter et al (2000)).

The relevance of hydration is predicated on the assumption that if the body's hydration lowers the mucus covering the vocal folds dries and becomes sticky and the increased viscosity results in a less smooth and regular vibration of the folds. This has been investigated in adults.

Akhtar et al (1999) investigated the effect of caffeine, known to be a dehydrating agent because of its sympathomimetric properties and diuretic effect, on voice quality, assessed by irregularity in vocal Fo. Their findings, albeit derived from a small number of subjects, demonstrated an increase in mean percentage of irregularity over time; however, they also found the residual effect of caffeine to be highly variable between subjects.

Selby and Wilson (1998) investigated acoustic changes in the voice related to mild dehydration and subsequent rehydration. They observed that, *"if subjects were experiencing any difficulty at all"* it was manifest on the initiation of phonation, and suggested that the hydration status may affect the initial cycles of vibration but thereafter the pattern is relatively normal. They speculated that (i) significant changes that could occur from dehydration and rehydration might be detected from analysis of the ELG Lx waveform, and listener judgements, and (ii) that systemic dehydration does not significantly affect voice Fo and regularity as the larynx may not be comparatively dehydrated by reduction in total body water. Their suggestion that hydration may affect the initiation of phonation is supported by the studies of Verdolini-Marston et al (1990) and Verdolini et al (1994) in studies of hydration (a) with changes in phonation threshold pressure and (b) phonatory effort, based on the assumption that laryngeal tissue viscosity changes *might* occur with changes in hydration level. A pilot study (Verdolini-Marston et al, 1990) which explored the effect of – (a) decreased relative environmental humidity, (b) decongestant mucolitics, and (c) liquid intake on phonation threshold pressure, demonstrated a relationship between phonation threshold pressures and tissue viscosity. Subsequently Verdolini et al (1994) reported that results indicative of an inverse relation between hydration level and phonation threshold pressure were strongly pitch dependent, (approximately 6% (about 0.19cmH_2O changes from dry to wet conditions at low and conversational pitches, compared to 21% (1.52cm H_2O) at high pitch). However this is qualified by the argument that large reductions in phonation threshold pressure associated with hydration were unlikely because phonation threshold pressures are generally low at low and conversational pitches.

4.3.2 *The relationship between voice fundamental frequency and aggravants*

Much attention is given to the effects of smoking. Strome (1982) refers to secondary smoking which is now considered to be more significant than was recognised previously and states that *"Cigarette smoke has a definite effect on the child's larynx"*, and reports children experiencing hoarseness attributed to the effect of smoke from parental use of cigarettes. This aspect is pertinent to the subjects of this study who may also sing at functions in a smoky environment.

4.3.3 *The influence of emotion*

Emotion is not quantifiable and pervades every situation and activity; it is only when extremes of emotion are apparent that they may become problematic. However, there may also be levels of emotion that are not manifest but have a subtle effect on behaviour.

Sensitivity to childrens' feelings is important, especially when they are in an environment where they may not feel able, or have the opportunity to express themselves openly; underlying and unexpressed emotions may affect the ability to sing, potentially causing vocal strain.

Williams and Stevens (1972) refer to the study by Fairbanks and Provonost (1939) on the effects of emotion on the acoustic characteristics of speech showing that average values and ranges of Fo differ from one emotion to another. While the main linguistic function of Fo changes is to identify the structuring of an utterance it can be used for emphasis or to express emotion; because Fo may vary because of adjustments which are not volitional, it can indicate emotional states. Baken and Orlikoff (1987) identify Fo as a critical parameter of speech and a crucial variable in singing, but suggest that phonatory Fo is not under as much control as it appears to be. From their own study Williams and Stevens (1972) concluded that it was possible to classify a speaker's emotional state from a sample of several seconds as (a) sorrow – reduced Fo and decreased range; or (b) anger or fear – increased Fo and range, as long as the normal Fo is known. Dankovicova and Paque (2004) examined various Fo parameters and found that portrayal of emotions of anger, sadness and happiness were each characterised by specific combinations of these parameters.

Anger	high intensity and slow articulation rate; rise-fall Fo pattern, (this was also a feature of happy speech).
Happy	higher pitch setting, in contrast to neutral, and sad
Sadness	mainly flat Fo, a narrow pitch range, low average Fo and low intensity

Williams and Stevens (1972) cite Lindsley (1951) to relate the effect of a disturbance to respiration on phonation:– *"respiration is frequently a sensitive indicator in certain emotional situations, especially startle, conscious attempts at deception and conflict. The respiratory pattern is frequently disturbed in anxiety states"*; an increase in respiration rate can result in an increase in subglottal pressure during speech raising the Fo, and shorter bursts of speech..

Also in certain emotional states the mouth and throat becomes very dry and Verdolini-Marston et al (1990), cited by Selby and Wilson 1998) found greater subglottal pressure was required for phonation when the vocal folds were dry.

4.3.4 *The influence of culture*

Moore and Holbrook (1971) applied reinforcement principles to investigate the modification of pitch. The results indicated that voice Fo is a manipulable operant response and that voice behaviour may be influenced by environmental reinforcement.

Children are susceptible to cultural /social influences and Hasek et al (1980), and Sorensen (1989) suggest that boys may be influenced by cultural stereotypes to adopt a lower Fo than the physiological optimum. Whiteside and Hodgson (1999) question whether sociolinguistic influences on the acquisition of intonation patterns affect the acceleration in Fo changes identified in their study of boys from age 8 years. They suggest that the development of Fo in children is determined by sociolinguistic factors as well as physical development, and that decreases in Fo standard deviation values may result from increased motor control, but that the intonation properties of the accent and language should be taken into account in interpreting data. Gunzburger (1987) citing Bladon, Henton and Pickering (1984) – *"males and females may in some speech communities speak more unlike (or like) each other than their vocal tract physiology would predict"*, suggest that *"an acquired, socially motivated factor must be part of a model of speaker normalization."*

CHAPTER V ASPECTS OF SINGING

5 *Introduction*

Bonet and Casan (1994) suggest that it is difficult to classify children's singing voices; a task that is complicated by developmental changes, particularly differentiation of physiological dysphonia from Fo and voice quality changes associated with maturation.

Considering the role of the cathedral choristers who are children – (but not exclusively pre-pubertal -) who perform both as soloists and as part of a mixed choir (ie including adults and not specifically a children's choir); who are theoretically amateur since they are not performing to earn their livelihood, yet may derive some pecuniary benefit from recording contracts etc.; who tour as part of an internationally acclaimed group, who train and perform whilst in full time education, and whose musical training is not confined to singing since they also learn to play at least one musical instrument to a high standard, it becomes apparent how special they are, exemplifying the comment of Bunch and Chapman (2000) that *"Trying to fit an aesthetic, kinaesthetic art into the medical research model has been uncomfortable at the best of times."*

The present study focuses on quantifiable aspects of singing but singing is an art – its propensity to provoke the thoughts and feelings of both the performer and the audience should not pass unremarked. The statement by Bishop William Warburton (1698-1779):

"I can't sing. As a singist I am not a success.
I am saddest when I sing. So are those who hear me.
They are sadder even than I am."

identifies, perhaps inadvertently, many aspects of singing: ability, expectations, perceptions of success, sentiment, and the emotional dynamic between a singer and the audience.

This study will not explore natural aptitude or emotion. Aptitude is undoubtedly relevant, especially to the choirmaster selecting applicants to a cathedral choir; it eludes both definition and easy measurement. Bohme and Stuchlik (1995) state that *"laryngeal capacity is altered by voice training."* and the enhanced skills of singers derive from the combination of inherent talent and development of that ability.(Murry and Zwirner 1991).

The interaction between music and emotion is profound. Scherer (1995) stated, *"the study of expression in singing needs to take into account the composer's emotional script, the singer's* *artistic interpretation and projection of a character's personality and affective state, and, finally, the singer's own physiologically based emotional state at the time of the performance."*

Although choristers are not required to portray a character, much emotional energy is put in to their performance and consideration has to be given to the emotional sensitivities of these young children. This aspects warrants investigation in terms of the psychological and social perspectives, but will not be discussed further here.

5.1 *Styles of singing*

The concept of singing is, theoretically, extremely simple; it is a process of uttering words to a tune. McKenzie (1956) regards singing and speaking as the same process, *"the one being merely a sustained and prolonged form of the other."* Hill et al (1995) quote the remark of a choirmaster that *"good singing is a controlled form of shouting."*

In practice research on the singing voice is extremely complex since it must take account of numerous variables such as styles of singing, the attributes of the individual or group of singers, and the environment in which they are performing.

Bunch and Chapman (2000) have compiled a list of nineteen types of singers which illustrates the diversity of singing styles, and nine categories of singers, according to what is referred to as the proven performance achievement:-

"Superstar	*Regional/Touring (often seasonal)*	*Singing Teachers*
International	*Full-time students of singing*	*Child*
National/Big City	*Local Community (often semiprofessional)*	*Amateur*

"Child" is defined as prepubertal.

5.2 *The Singers' Formant*

A characteristic of the voice of the trained singer (classical) is the ability to control the expired airflow, sustain phonation and modulate volume more effectively than untrained singers who rely on glottal adduction to increase loudness resulting in pressed phonation and a comparative reduction in the amplitude of the voice source fundamental. (Murbe et al 1999).

Sundberg (1974) describes the 'singing formant' as *"a high spectrum envelope peak near 2.8kHz characteristic of vowel sounds produced in male Western opera and concert singing."*

and Murbe (1999) identifies a prominent singers' formant as a requisite of male voices, (bass, baritone, tenor and alto).

The 'singers' formant' is produced when the larynx is lowered, modifying the dimensions of the pyriform sinuses and the pharynx, (this refers to the particular articulatory behaviour, although of the larynx is also associated with ageing, (Sundberg 1974. 1998)). The lack of the 'singing formant' in the higher range of a soprano voice is attributed to the inability to maintain the *"acoustical mismatch between the pharynx and larynx tube"*,(Sundberg 1974). White (1999) refers to the difficulties in formant frequency analysis of high pitches as a reason for the lack of "reliable data regarding children's spoken or sung vowel formants."

5.3 The Singing Environment

SOLO AND CHORAL SINGING

Modes of musical performance in solo and choral singing are entirely different to the extent that some teachers consider that an individual singer cannot master the two types of voice use, (Rossing et al. 1986)). As with many studies of the singing voice acoustic comparisons have been based on adult singers. However, some of the aspects identified may also be relevant to children.

A study of eight bass/baritone singers recorded singing solo and in a choir demonstrated that in the choir the voice levels were influenced by what they were hearing from other singers, but in solo singing significant differences were recorded between the levels of the singer and the piano accompaniment. The subjects were highly skilled as choral and solo performers, which the authors consider exceptional, but all subjects were found to generate more energy in choral singing (measured by long-time-average spectrum(LTAS) in the lowest frequency range, compared to the performance in solo singing, suggesting solo and choral singing differ in respect of both articulatory and phonatory behaviours. (Rossing et al 1986).
A subsequent study (1987) comparing soprano solo and choir singing again identified different behaviours:-

(i) The singers produced more energy in the frequency range 2 – 4kHz in solo singing, compared to choral, (this was not found by Keilmann (1998) who reported less energy in the range 2.5Hz – 6kHz in solo singing).

(ii) Significant differences in the spectral characteristics in this frequency range were identified between singers.

(iii) More vibrato was used in solo singing, (this was not found by Keilmann (1998) who reported that experienced singers used more vibrato in choral mode).

Ternstrom (1991) points out that to achieve the blending of voices required for a choral sound the choir singer must adjust loudness, pitch and timbre. He investigated several aspects of choir singing and found that the reverberation properties of the environment influence the chorus effect, with a tendency for singers to adjust their performance to the acoustic environment. (Curwen (1891) explains that singing is influenced by the environment and that, for example, at St.Paul's Cathedral, *"owing to the size of the building, a tremendous volume of shrill tone has to be cultivated, ..."* Marshall et al (1978), cited by Ternstrom (1991) found that the loudness of reverberation was considered more significant than the timing. Keilmann (1998) refers to the findings of Ekstrom (1960) that experienced singers did not depend on immediate auditory feedback as much as inexperienced singers, and of Siegel (1980) that young children (ages 5years and 8years) are more sensitive to this kind of delayed auditory feedback than adults.

The findings of these studies indicate that there are significant differences between solo and choral singing which may be pertinent to the training of choristers, although studies of childrens' voices focus on voice range and features of voice change rather than the behaviours and characteristics of choral singing.

Keilmann (1998) investigated seventy-six children and young adult singers, (in three groups of at least ten males and ten females; group mean ages, 12years, 15years and 18years) singing solo and choral mode and concluded that children's voice production is affected differently by surrounding sounds (i.e.a choir), than experienced adult choral singers'. The behaviours observed were:-

A tendency to sing more loudly in choral mode.

A tendency to shorten the phrase in solo mode

Not reaching a pitch target immediately was more apparent in choral mode.

No differences were identified in the precision of intonation in the two singing situations; however, differences were reported between the youngest group of males and females, with the intonation of the males being least precise.

5.4 *Singing Development in Children*

Singing development may be spontaneous, encouraged through singing activities at home and school, or as a learned behaviour through specific singing training. The choristers fall into the latter category; however, the other two may contribute to the reason for selection to the choir school.

Welch (2000) identifies several factors which influence musicality such as *"basic biological potential, maturation, experience, opportunity, interest, education, family, peers, and socio-cultural context."* and refers to research which demonstrates that singing development is also influenced by age, sex and singing task and schooling.

Several factors may influence a child's interest and ability to develop their singing skills.

- The type(s) of music the child has been exposed to and the positive or negative experiences generated. Welch (2000) refers to interpretation of a child's musical behaviours by *"adult /'expert' musicians in relation to expected norms"*, particularly with respect to judgements of being 'out-of-tune'. Previously Bonet and Casan (1994) commented that assessment of children's singing voices was dependent on the assessors' subjective judgement of pitch accuracy and quality.
- Pitch discrimination skills. Whereas some researchers suggest this is an inherited skill (Seashore (1938), Bachem (1940) and Revesz (1953) cited by Murry and Zwirmer (1991), (1990) found subjects who had substantial training in vocal music more accurate in matching Fo by three-fourths of a semitone than those with less training, and Welch (2000) reported improvement over time from a longitudinal investigation of pitch matching skills in children aged 5 years, 6 years and 7 years.
- The ability to learn the melodic contours compared to the ability to learn a song. Welch (2000) found pitch matching was more accurate in non-song tasks because the child was less inclined to focus on the words and concluded, *"singing competence is task related, with simpler vocal tasks generating the greatest vocal pitch accuracy and also being subject to the clearest improvement"*,
- The relationship between the accuracy of pitching notes and the perception of the sung notes, since pitch perception is influenced by loudness and timbre, as well as by frequency, Howard and Angus (1997). An assessment of pitching skills of children between the ages of 8years and 11years using a computer based system, (SINGAD –

SINGing Assessment and Development - Howard and Angus) demonstrated age, gender and task influences on the accuracy of pitch matching ability. The girls develop pitch matching skills at an earlier stage than boys, (also found by Welch et al 1997) with accuracy improving both over time and on harder tasks. The influence of timbre was also found by White et al (1996) who reported that responses of five-year-old subjects were influenced by their perception of electronically generated stimuli in terms of the timbre rather than pitch.

5.5 *Singing Range in Children*

Recent studies of vocal function in children have advanced both knowledge and perceptions but, especially in the context of this study, it is worth referring to the origins of the interest in children's voices, rooted in early Church music. Van Oordt and Drost (1963) refer to this 'cultivated form' of children's singing giving rise to the misconception that the child's voice had the same range as the mature female voice. These researchers did not have access to the technology available today to determine Fo range accurately but identified a musical frequency range for children at 8 years of an octave, expanding to two octaves, and endorsed the view of Hartlieb (1930) that the musical range develops within the physiological range, increasing not just with age, but also with exercise McAllister et al (2000) caution the importance of distinguishing between the true physiological range and *"a range consisting only of tones that the subject and / or the experimenter regards as 'acceptable'"*.

McAllister et al (2000) found the dynamic range of children aged 10 years to be restricted compared to female adults, but also found the average voice range profile (VRP) of boys with mutational voices approximated towards more adult VRP values in the upper part of the range.

However, Pabon et al (2000) from a comparison of phonetograms of children and female adults found both pitch range and maximum phonation levels similar (average adult female frequency range A sharp to C3, average child's range F to F3), the lower limit of the adult voice being slightly lower. Pabon reported an increase over one year in the high frequency end of the pitch range of choristers age between 8 years and 15 years; (he attributed an increase in the top range to artistic development, and an increase of *"about two semitones per year"* for lower pitches to general growth, with no distinction between singing and non-singing boys, (although all subjects in the study were member of a boys choir)); whereas

McAllister et al (2000) reported a mean Fo range of 27 S/T (185Hz – 880Hz) in 15 children which included children with deviant and mutational voices; they studied music as part of their school education but did not have any particular training in singing.

It is important to look at the behaviours as well as the result; whether the children are aware that the pitch they produce does not match the target, any efforts made to correct this, and, particularly in view of the finding of Bonet and Casan (1994) of a 20.2% prevalence of dysphonia in a children's choir, any behaviours that might provoke hyperfunction.

5.6 ***Singing Training***

Usually children are taught to sing by adults who have developed their own singing technique as adults. Lovetri et (1999) comment, (with reference to vocal qualities for music theatre), *"Because singing in these styles is learned mostly through listening and trial and error, many singing teachers are not aware of how these qualities happen and cannot teach their singers how to sing in these qualities."* The behaviours which adults use, and it may be surmised, demonstrate, to achieve the required result may be inappropriate to the children. Many church choirmasters are first and foremost organists. (Hill et al. 1995), and many smaller choirs may not have access to singing teachers.

Teachey et al (1991) comment that whether the differences between trained and untrained singers are the result of the *"innate or superior physiologic endowment"* is not known, but cites Brown et al (1988) who attribute the enhanced performance of trained singers to the training.

One of the skills is matching the vocal pitch to a pitch target, (this may be another singer, or an instrument), and these researchers question whether right hemisphere function, training or experience influence the speed and accuracy of pitch matching.

The results of studies of accuracy reaching a vocal target cited by Murry and Zwirner (1991) demonstrated that singers do not necessarily have an enhanced motor system. The findings of this study indicate the accuracy of pitch matching ability is improved by training and experience, with more experienced singers responding faster and more accurately than less experienced singers.

5.6.1 <u>*Training Choristers*</u>

A fascinating insight into the training of choristers is provided by John Spencer Curwen (1891) with reference to the experiences and advice of other choirmasters. Commenting on 'The Healthfulness of singing' emphasis is given to not straining the voice. *"The boy's voice, though an immature organ of delicate structure, is capable of much work, providing only that its mechanism be rightly used and not forced."* Advice includes the selection of choristers, *"The Art of Managing Choir Boys"*, *"management of the breath"*, posture, pronunciation and tone. (Appendix 1).

It is apparent from this text, that although many of the social aspects have changed, - such as the number of boys wanting to become choristers and demographic changes, key issues regarding training and the care of the boys' voices were being questioned in the 19th Century, and remain unanswered in the 21st Century.

A review of later references relating to training choristers highlights the ambiguity around this aspect.

McKenzie (1956) states that *"The success that is possible with boys' changing voices during the adolescent period depends a good deal on the way the voices have been used in preadolescence."* McKenzie emphasises the importance of the speaking voice which, it is stated, *"is the most reliable in estimating the status of the singing voice at any time during the adolescent period."* and that singing should not be forced, should be properly produced and within an easy range.

The main theme of McKenzie's text is that as the chorister's voice lowers he should be transferred to the alto section of the choir. McKenzie also refers to the selection of music appropriate to the boys' voices and the differences between American and English church choirs.

'A Handbook for Choir Directors and Trainers' (Hill et al 1995) provides a comprehensive overview for training choirs and suggestions for warming up, and voice production and projection exercises, including relaxation, posture and support, and breathing exercises.

Bragg (2002) refers to *"three basic ingredients in the art of singing: posture, breathing and phonation or sounding."*

Neither of these texts comment on whether or not boys should sing while their voice is changing or the learning of the words and music. Hill et al (1995) refer to Henry Coward's comment that *"it was foolish to expect a choir to give full musical and textual expression until both notes and words were well-known."*; borne out by the finding of Welch (2000).(Curwen 1891 referred to choirmasters assessing reading competency when selecting choristers).

Blatt (1983) suggests that the time of voice change is the right time at which to train the voice and outlines a training programme to facilitate developing the voice. Training is defined as *"forming and directing by instruction, discipline, and drill; training includes diet, exercise, and hygiene."* The children assessed were in the age range 7–16 years and were either already receiving individual training, or were students in a programme for gifted and talented children. The success of the programme was judged on the voice range, and the absence of any vocal difficulties because of voice 'breaks'. These findings are not supported by any objective evaluation which Blatt suggests would enhance perceptual judgements.
A notable aspect of this work is the attention given to 'Physiologic Occlusion', (referring to *"the teeth and the supporting soft tissues, the temporomandibular joints and attached ligaments which limit movement, the masticatory musculature, and the jaws (maxilla and mandible)).* Blatt points out the relevance of oral health because *"a disturbance of one part throws the entire system out of balance."*(this point is also made by Carroll et al (1996), who refer to compensatory behaviours used to adjust to imbalance in the respiratory, laryngeal and resonatory mechanisms). It is not unusual for adolescents to have to wear a dental appliance because of alignment or other orthodontic problems and this is an important consideration.

Barlow and Howard (2002, 2005) investigated the effect of training and regular singing on the voice source using electrolaryngography. These researchers did not find any indication that voice training from an early age had any adverse affects on these subjects but consider their findings inconclusive in respect of training male voices through adolescence; (the subjects did not undergo any laryngeal examination).

McGraw(2002)(www.hartline.net/EMEA/journal/journal5/kindergarden/html 10.02.2004) discusses the change of practice (in American musical education) from teaching children to use a 'head voice' and extend the range down, to teaching them to sing in a 'comfortable range' (chest voice) and extend the range upwards, and refers to research which indicates that this results in restriction rather than expansion of the range, and pitch accuracy problems.

McGraw (2002) suggests that the choice of pitch range for singing in the early stages of childhood is significant to the later development

5.7 *Laryngeal position in singing*

Studies of laryngeal position in singing relate to adult performers. Shipp (1975) investigated whether the low larynx position was a function of training by comparing the behaviour of professional singers (baritone) to non-singers (males age 20years and 29years).Measurements of the vertical laryngeal position taken from still photographs demonstrated that low frequencies were produced by the non-singers with the larynx at rest or lower than the resting position, and the larynx position was raised as the frequency was raised, (the range identified in one subject was from 16mm below the resting position to 13mm above resting position), whereas the singers did not raise the larynx above the rest position and lowered it as the frequency increased thereby maintaining or increasing the vocal tract dimensions. No relationship was found between the amount of voice training or the vocal quality.
Lovetri et al (1999) the relationship between vocal qualities and muscular and structural changes in female musical theatre singing using fiberoptic rigid and flexible endoscopy to visually evaluate the configurations; although finding that adjustments were made to the tongue, palate and oral pharynx according to the tonal quality, these researchers noted that these adjustments are idiosyncratic.

5.8 *Articulation in singing*

Anecdotal evidence suggests that many people are unable to distinguish sounds, and even words sung at high frequencies. Hollien et al (2000) refer to studies of perceptual recognition, which suggest correct identification varies from 52%-93%, (Fairbanks and Grubb. (1961)); that difficulty identifying vowels is directly related to raised Fo, (Benolken and Swanson, 1990), specifically for Fos above 392Hz (G4) in males, (Morozov 1965).It is notable that Morozov reported that isolated vowels produced by female singers at this frequency were intelligible, which suggests other factors influence perception. Hollien et al (2000) found that intelligibility is influenced by the co-articulatory environment but if the Fo equals or exceeds the usual first formant, isolated vowels are unlikely to be correctly identified; the higher Fos were found to influence the usual first formant. In contrast to the finding of Morozov (1965) they reported that these behaviours were particularly demonstrated by females singing at high pitches.

A significant amount of air may be lost during the articulation of voiceless consonants. Rothenberg et al (1987) investigated how singers modify articulation and co-ordinate the laryngeal and articulatory behaviours to avoid excess loss of air as the vocal folds are abducted, and identified five possible techniques:-

A slight increase in lung pressure before aspiration allowing a lung pressure drop during the aspiration.

By applying tighter articulatory constriction.

Sustaining the articulatory constriction slightly longer.

Less glottal opening

Faster glottal closure. (the speed of vocal fold adduction and abduction by an operatic-style soprano was reported as ~125ms in singing compared to 200ms in speech).

These researchers concluded that a number of techniques were applied by the subject (a soprano singer) in modifying vowels and consonants to the higher pressures used in singing, and suggest that *"improper control of air flow can have significant esthetic and/or medical implications."*

Reference to the literature on singing demonstrates its complexity. From a review of a range of work it becomes apparent that there is very little information available regarding the particular behaviours of children singing and that much of the work training children is derived from the adult model, which may not be appropriate.

CHAPTER VI EVALUATION OF VOCAL FUNCTION

6 *Introduction*

Advances in technology enable aspects of voice to be measured and described quantitively; however, the voice is multidimensional and influenced by many variables. Whereas any one measurement is unidimensional and only provides information on a particular feature.

Moses (1954) observed:-

> *"The parts must be isolated for the sake of analysis, but we should always remember that this is an artificial process."*

Abberton et al point out, *"The aim of research in speech pathology is to provide explanatory accounts of disabilities rather than descriptions..."*(1989). Fundamental to this is identification of the norm by quantitative methods as a basis for evaluating the extent and manner in which perceived auditory voice quality diverges from it.

Measurements can usefully be related to normal data where it is available; however, as reported by Williams et al (2005), *"Currently, there is no existing published empirical longitudinal data on the singing behaviours and development of choristers who perform in UK cathedrals and major chapels."*; this also applies to data on the speaking voice of choristers.

Interpretation of physical data should also take account of the many variables influencing it. Barry et al (1991) refer to the *"speech communication chain"* which provides a useful concept to describe such a multi-modal dynamic process. The voice source component is typically measured by the Fo of vocal fold vibration; and Fo is often used as one of the criteria of normal voice for specific subject groups (such as Robb and Saxman (1985) in relation to developmental trends in children; Robb et al (1989) in relation to infants; Hollien et al (1994) and Pedersen et al (1986) in relation to adolescent males. Vuorenskoski et al (1978) in relation to normal and abnormal growth; Debruyne and Decoster (1999) and Decoster and Debruyne (2000) in relation to age; Laukkanen et al (1999) in relation to Finnish speakers).

6.1 Measurement of the vocal fold vibratory cycle

"... what constitutes "normal" laryngeal vibration?" (Gelfer and Bultemeyer (1990))

A pre-requisite of normal voice production and therefore a criterion for classification of normal vocal fold vibration has conventionally been considered to be complete antero-posterior vocal fold closure during each vibratory cycle. This assumption may originally have been more the consequence of limitations of examination techniques than based on sound evidence, a situation obviously influenced significantly by the advent of videostroboscopy. Sodersten and Lindestad (1990) refer to ambiguity around this issue and cite studies reporting a posterior chink regarded as a common finding in normal subjects (gender not specified), and others where it is regarded as pathological. The same researchers comment that clinical studies typically focus on the membranous portion of the vocal folds which are more susceptible to laryngeal disease, rather than the posterior cartilaginous part.

The criterion for normal used by Sodersten and Lindestad (1990) was *"a normal larynx as observed during mirror laryngoscopy, (i.e. pale vocal folds with even edges, no swelling, normal abduction and adduction)."* This and similar definitions eliminate pathological or disordered larynges and comply with the medical model of laryngeal condition and gross function; this is enhanced by evaluation of the mucosal wave using stroboscopy where appropriate. It is debatable whether this is in fact sufficient or whether, as Gelfer and Bultemeyer (1992) imply a definition of 'normal' should be based on a protocol including control of frequency and intensity and a wide range of speakers in respect of age, gender, and social class.

For the purpose of this study the medical model of gross configuration, vocal fold condition and mobility, has been used with vocal fold vibration measured using ELG.

6.2. Instrumentation

Physical measurements can be used to support perceptual (subjective) judgements which, with reference to clinician's judgements Kent (1966, cited: Wuyts et al 2000), considers *"the final arbiter in clinical decision making and often provide the standard against which instrumental measures are evaluated."* by relating perceived auditory voice features – quality and intonation - appropriately referred to by Fourcin et al (2002) as *"what is so obvious to the ear of the listener".* to laryngeal excitation features of mode, and rate of vocal fold vibration.

Fourcin et al (2000) propose *"the really important aspects of voice are those that can be heard"* and identifies the dominant dimension as pitch.

Abberton and Fourcin (2000) state the *"type and rate of vocal fold vibration provide the essential skeleton of normal speech communication"*.

The choice of system used to assess vocal function is determined by several factors, including cost and ease of application. Techniques such as high-speed photoglottography, ultrasound and electromyography are not typically used routinely. (ELG) has proven application as a clinical tool to support diagnosis, facilitate feedback in therapy and provide quantified comparators of vocal function. As a non-invasive procedure it can be used without ethical or clinical restrictions in a busy voice clinic. It provides information on the vocal fold vibratory cycle without interfering with phonation or continuous speech and is not compromised by extraneous noise. The increasing use of ELG in NHS clinics in the U.K. is enabling cross-referencing and contributions to establishing broad data bases, as well as the continuing development of its use in therapy (Wechsler 1977, Carlson 1988), a primary aim in its development having been that it should *"find direct practical application in therapy and clinical situations"*. (Fourcin 1981)

It is particularly relevant in working with children because it is not a daunting apparatus which children – especially those with some experience of computers – regard as another computer game rather than a piece of clinical equipment.

Realistically *"Practicality, cost and expenditure of time determine the equipment and the utilization*". (Klingholz 1990).

The merits of ELG are:-

- It is non invasive
- It does not inhibit speaking enabling analyses of a substantial sample of continuous speech.
- Recording via the electrodes is impervious to extraneous noise.
- It provides simultaneous visual feedback to patients
- The analyses is concise, is generated quickly and can be related to perception and production.

6.2.1 *Electrolaryngography*

The system used in the present study (Speech Studio), has been developed from the laryngograph designed to monitor vocal fold closure in the laryngeal excitation component of speech production, (Abberton et al.1989; Fourcin and Abberton 1971, (cited Wechsler 1977); Fourcin 1981; Fourcin 2000);

The principle of ELG is the measurement of variations of electrical impedance resulting from the opening and closing phases of the vibratory cycle of the vocal folds.

By placing an electrode externally in the middle of each ala of the thyroid cartilage at the level of the true vocal folds the current flow between the vibrating folds which varies according to vocal fold contact can be measured with an increase in contact area showing a correlating increase in current flow.(Fourcin and Abberton (1971), Abberton and Fourcin (1997), Howard (1998)). It is not dependent on complete antero-posterior contact to generate a signal, giving it broader application in clinical practice. The standard electrodes used are 3.2cm for adults and 1.6cm for infants. However as neither of these sizes was suitable for the subjects in this study 2.2cm size electrodes were made to specification. The electrodes have an outer guard ring and an inner conductor but no active elements. Fourcin (1981) describes one electrode with a 4MHz transmitting voltage applied between the conductor and guard ring, and the other providing a current pick up with dissipation of approximately 30mW at the subject's neck and only microwatts at the level of the vocal folds.

The electrodes are usually held in place by an elastic neck band. The placement of the electrodes is important, the three most typical difficulties resulting from, (i) size of neck / adipose tissue, (ii) displacement, particularly relating to laryngeal movement and (iii) interference.

6.2.2 *Electrode Placement*

Vertical larynx height has mostly been studied in terms of correlation to Fo (Ashby 1983; Shipp and Haller (1972): Shipp (1975); Sundberg (1997)) but is obviously relevant to electrode position. Ashby (1983) reports a variation in larynx height during speech of up to 2cm in adult male subjects, with visible changes in the position of the prominence of the thyroid cartilage observed. Sundberg (1997) identified a difference in elevation of the larynx between singers and non-singers and reported lowering of the larynx only on increasing frequencies and elevation above resting position rarely occurring when decreasing frequencies. Although seeming at variance with most commonly observed behaviour of raising the larynx in relation to higher Fos and lowering for low frequency phonation Shipp (1975) also identified progressive lowering of the larynx for frequencies over 300Hz. However elevation of the larynx as vocal frequency was raised, and downward movement as vocal frequency was lowered was identified more consistently in young male subjects who had no singing or voice production training. Hamlet (1980) reports that positional laryngeal adjustments occur primarily in the vertical plane in running speech and identified this as the most important dimension for fine lateral resolution for ultrasonic measurement.

The extent of excursion appears to vary significantly as recorded in Shipp's study (1973):-

<u>Discrete Phonation Frequency change</u>: from 4mm to 22.5mm excursions.

<u>Glissandi</u>: from 6mm to 14 mm excursions

In one subject the extent of vertical laryngeal excursion could not be measured because of elevation to a point where the thyroid prominence became obscured by submandibular tissue.

A direct relationship between thyrohyoid muscle activity and vertical larynx positioning was identified by Shipp and Haller (1972) and vertical laryngeal position and thyrohyoid and sternothyroid muscle activity by Shipp (1975) who also refers to the positioning of the larynx coinciding with a preparatory respiratory gesture and cites a hypothesis of Mitchinson and Yoffey (1947) that laryngeal lowering may be related to diaphragmatic muscle contraction for deep inspiration.

The subjects in Shipp's study were supine for the assessment and phonated only on the vowel [a], both of which factors may have some relevance. Perhaps more significantly the study was limited to subjects who had an *"exaggerated"* thyroid cartilage prominence, characteristic of adult males with slender necks, to enable effective filming of displacement of the anterior neck tissue by the thyroid cartilage.

While it is relatively easy to place electrodes appropriately on the thyroid of a thin-necked male, it is not necessarily a straightforward procedure, especially in women and children with a very small thyroid, and in subjects with well developed muscle and, or, a substantial layer of adipose tissue.

Although it is usually possible to identify a placement that produces a satisfactory signal for a sustained vowel with a steady laryngeal position, this may be adversely affected by laryngeal movement as previously referred to.

Colton and Conture (1990) suggest subjects may hold the electrodes on their neck, or with children, the experimenter may hold them; this is not recommended by the manufacturer. Colton and Conture report obtaining good signals in children of 3 years of age, but that it is easier in children of 4 years and over and acknowledge problems of attention and co-operation.

The subjects in this study were accustomed to a rigorous and disciplined regime of choral training so were encouraged to participate in and enjoy this procedure in a relaxed and convivial manner. This, if anything, made them even more eager to co-operate and tolerant of sometimes fairly protracted experimentation with electrode placement. Problems experienced were mainly because of the size of the thyroid which in the youngest child (8.01years) had a depth of only 13.5mm. Although Colton and Conture (1990) refer to the larger angle of the thyroid of children creating a wider current path, the overall width would still be significantly narrower than a young adult male with a smaller angle of the thyroid. Kitzing (1990) likewise refers to the size of the larynx in relation to EGG amplitude since glottal vibrations account for only ~ 1% of modulation of total impedance.

Colton and Conture (1990) refer to an investigation into the relationship between neck size, subject size and total neck impedance (Rothenberg and Rothenberg unpublished manuscript. 1989) which identified a moderately high correlation between total neck impedance and neck circumference. Reference is also made to the effect of well developed extrinsic musculature of the neck reducing the current flow of the electrodes and idiosyncratic variations of electrical resistance of skin. (Colton and Conture, 1990; Kitzing 1990).

Problems of electrode placement can therefore challenge the reliability of the signal and must be taken into account in interpretation of data. If the placement is satisfactory conduction through the tissues of the neck is reasonably good and as the contact between the folds increases with glottal closure the impedance is diminished, the underlying principle being monitoring of variations in the area of contact of the vocal folds.

Kitzing (1990) emphasises that in the absence of detailed knowledge of the cause of impedance changes identified by glottography, even this is an approximation, and also questions, again in the absence of detailed knowledge, the relevance of vocal fold contact area variations to the acoustic voice signal citing Childers et al (1990) who refer to the electroglottogram as *"a poorly understood tracking device, in its present form ... not capable of contributing much to clinical diagnosis and treatment of voice disorders"*. An opinion which may have some validity but fails to reflect the value of the descriptive function of EGG/ELG in relating symptoms to clinical diagnosis and facilitating the selection of appropriate treatment techniques.

Baken (1987) points out that as all structures between the electrodes and even proximal structures interact with the current flow the output *"is not merely reflective of laryngeal phenomena"*, however although this may affect scientific and research purposes, consistent application will render comparative data clinically useful.

Baken also points out that to avoid confusion with laryngography (contrast-medium radiological imaging of the larynx) the term EGG should be adhered to, although the glottograph refers to the glottis, i.e. the area of aperture, which the ELG does not.

6.2.3 *The Lx waveform*

ELG (Fourcin & Abberton 1971) and EGG (Kitzing 1986) involve application of the principle of electrical impedance generating an output waveform representing current flow, attributed to Fabre (1957). However whereas Fabre referred to information about the glottal opening pattern, subsequent research (Fourcin (1981.1986). Abberton and Fourcin (1989,1997) Fourcin and Abberton (1971)) identified the representation of the vocal fold closure during vocal fold vibration. The ELG output (Lx) waveform is consequently positive-going as vocal fold closure increased with the peak corresponding to maximum closure, or minimal glottal aperture area, whereas the EGG output is conventionally inverted. (Howard 1998).

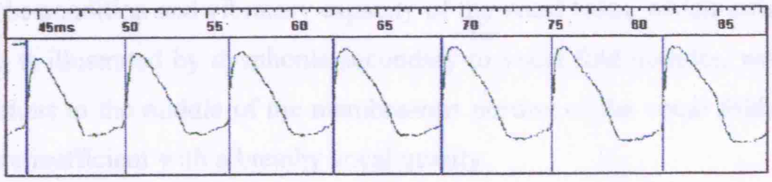


Diagram 5. Lx waveform with markers identifying individual pitch periods ($\overline{T}x$) (Fourcin et al. 2002)

Changes in vocal fold contact area modify the inter-electrode current flow and determine the configuration of the waveform. The vocal fold vibratory cycle is simplistically represented as a waveform comprising the closing phase; maximum contact; opening phase and open phase from which detailed analysis of cycle by cycle variation of vocal fold vibration can be derived, (Howard 1992)

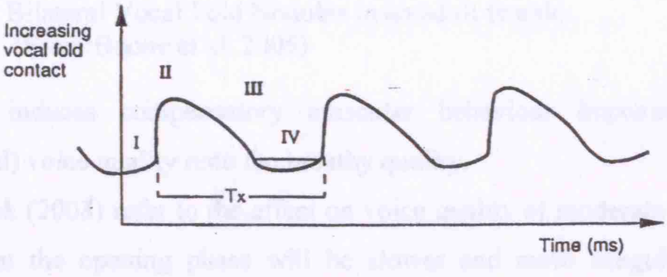


Diagram 6 Representation of the ELG waveform

	Waveform	Vocal Fold Activity	
I	Steep rising edge	Closing phase	
II	A maximum peak	Maximum Closure	Closed phase
III	A shallow falling edge	Opening phase	
IV	A trough *"essentially consistent with time"*	Open phase	Open phase

Table 7. Phases of the vocal fold vibratory cycle.

When the vibratory cycle is affected by a problem of structure or function of the vocal folds, this is reflected in the configuration of the waveform. (Wechsler 1977). To date available information has not provided definitions of waveform configuration related to specific pathologies; however interpretations of the Lx waveform can be made on physical principles of the mass, stiffness and contact.

Kitzing (1990) shows that EGG waveforms can show "largely normal configurations" despite the present of laryngeal carcinoma; however, ELG is not intended to be diagnostic and any measurement of vocal function should be supported by ENT examination and perceptual evaluation.

Fourcin (1982) explains the importance of the closure phase, since the contact activity is affected by the condition and vibratory capacity of the vocal folds, which influences voice quality. This is illustrated by dysphonia secondary to vocal fold nodules, where bilateral epithelial lesions in the middle of the membranous portion of the vocal folds renders the glottal closure inefficient with a breathy vocal quality.

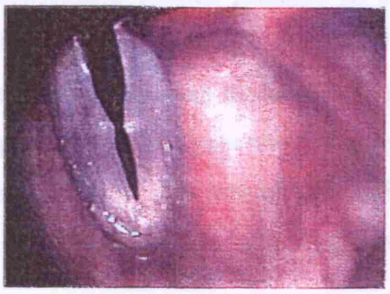


Diagram 7 Bilateral Vocal Fold Nodules in an adult female.
(From:Boone et al 2005)

This in turn induces compensatory muscular behaviour imposing a constricted (hyperfunctional) voice quality onto the breathy quality.

Fourcin and Ptok (2003) refer to the effect on voice quality of moderate unilateral paresis and explain that the opening phase will be slower and more irregular, (although the closure epochs may be fairly regular), causing impairment to the voice quality features which are dependent on closed phase definition and regularity.

Fourcin identified five points of the waveform:-

"1 *Uniform Lx peaks are likely to be associated with a correspondingly uniform acoustic signal.*

2 *Sharply defined Lx contact implies good acoustic excitation of the vocal tract.*

3 *Long closure duration (contact + separation) is likely to be associated with well defined, relatively undamped formants.*

4 *Regular sharply defined contact periodicity will give a well defined pitch.*

5 *Progressive change in sharply defined Lx period lengths will be associated with a smoothly changing voice pitch."*

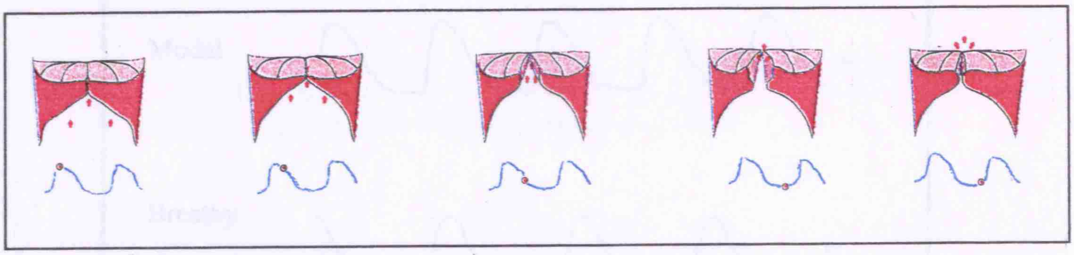


Diagram. 8 The waveform related to the closing and opening phases of the vocal fold vibratory cycle

The rapid closing and consequent sudden increase in conductance is represented by a steep rise. (Carlson 1993). The frequency of the vocal fold vibration is derived from measurement of the time interval between the commencement of the contact phase, (Tx. ie closed phase + open phase = Tx), to generate a frequency value (Fx) – described as an instantaneous value. (Fourcin 1981). This provides Fo estimation (Fo = 1/Tx). An Fx trace delineates the frequency of the vocal fold activity over time.

When vocal fold vibration is impaired the relative length of the phases change, and the pattern of the Fx trace is disturbed, as shown by comparison of a speaker with vocal dysfunction.

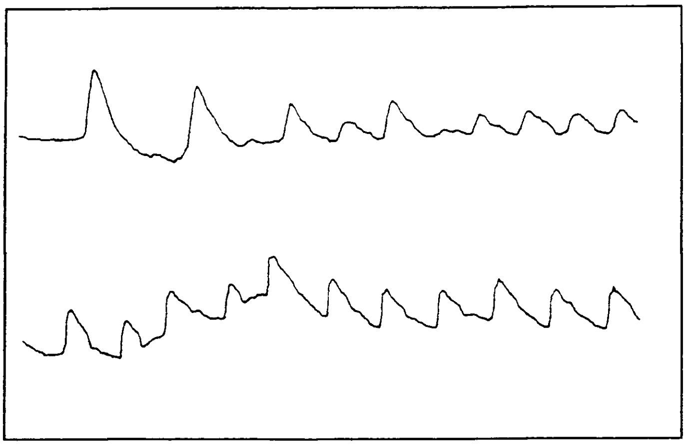


Diagram 9 Examples of abnormal waveforms.

This method of representation of the vocal fold activity forms the basis of what Fourcin (1981) describes as the *"conceptual simplicity of using vibration regularity as an index of performance."*

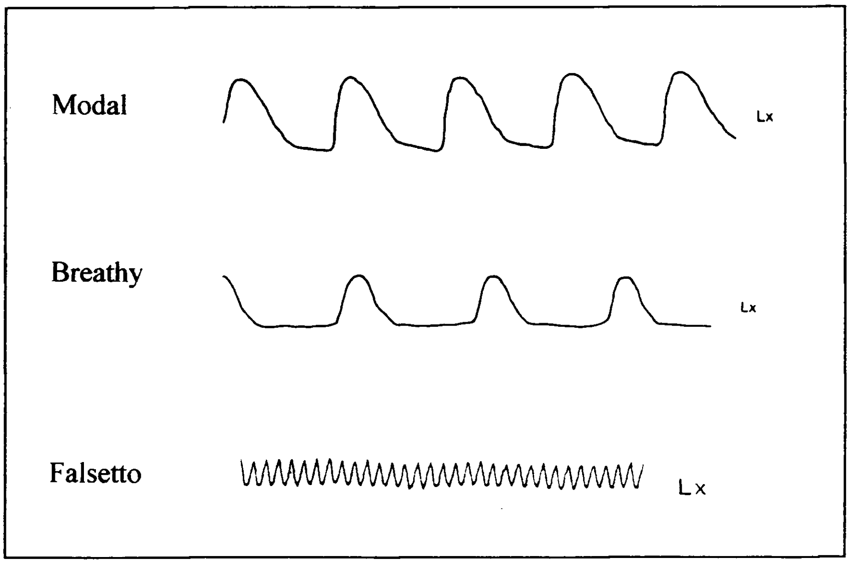


Diagram.10 Examples of waveforms derived from different voice qualities.

A breathy voice quality results from incomplete vocal fold adduction because of incomplete closure over a portion of the vocal fold length (glottal chink), or is characterised by a short closed phase and longer open phase. The Lx is periodic with the perceived breathiness – noisiness of the acoustic signal only evident in the open phase of the glottal waveform.

Falsetto is manifest at the upper end of the female Fo range, and is characterised by a shorter cycle time, with the Lx waveform closing gradient being less steep, and the gradients approximately equal at opening and closing

Normal voice does not demonstrate perfect periodicity but is typically characterised by small differences between adjacent pulses, so perceptually a voice without irregularity sounds mechanical or robotic,(Deliyski (1993), Orlikoff (1989), Titze (1991); therefore, a realistic quantitative evaluation of vocal function must embrace all components regular, and irregular.

Abberton et al (1989) note that a speaker using modal voice over the greatest part of the speaking Fo range may show creaky voice (vocal fry) at the lower end of the range and falsetto voice at the upper end of the range; this is illustrated by the speech and Lx waveforms.

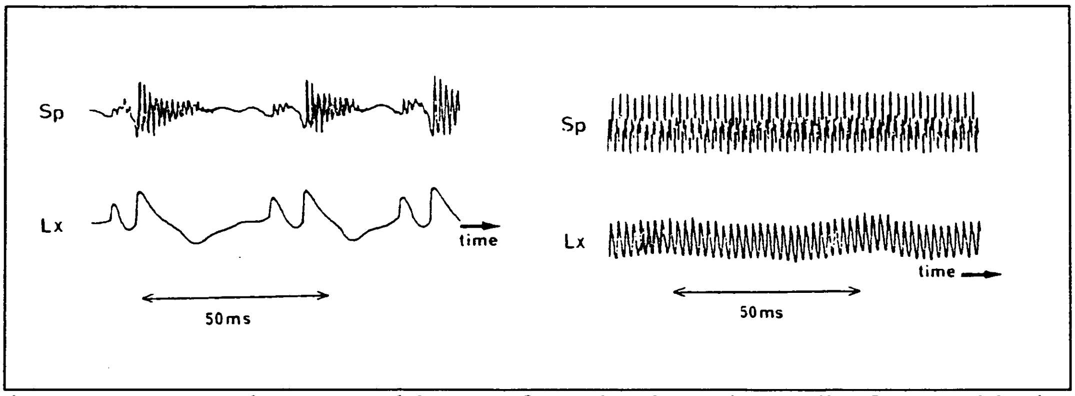


Diagram 11 Speech output and Lx waveform showing voice quality for vowel in the word 'dart': (Adult male).(Abberton et al. 1989)

6.3 *Speech Studio Analysis*

The system used for analysis of data in the present study generates information at two levels, explained by Howard (1998):-

> *"a macro level, where the input speech data lasts at least 2 minutes, and a micro level, where short speech inputs are used and the outputs from individual Fo analysis can be inspected on a cycle-by-cycle basis."*

6.3.1. *Microanalysis*

JITTER is a measure of temporal roughness derived by comparison of adjacent vocal fold vibratory cycles and is indicative of the stability of the vocal fold vibration.

Although sustained vowels are frequently used for clinical voice measurement (Linville (1988); Linville et al (1990); Horii (1980); Orlikoff and Kahane (1991)), our ability to detect pitch regularity in sustained vowels differs substantially from the ability to hear this feature in connected speech. The production of a sustained vowel may not reflect the vibratory behaviour used in continuous speech. Fitch (1990) found measurement of vowel Fo significantly different from reading or spontaneous speech and therefore not an accurate representation of habitual frequency. A subject asked to sustain a vowel at 'comfortable pitch' will be using the preferred mode of vibration and probably self-monitoring to choose the most effective pitch. If a subject repeats a vowel several times and one production which is not the first used for analysis (as in the studies by Horii, (1980), and Brown et al (1990)), there may also be an element of rehearsal. Sustained vowel production excludes the laryngeal changes related to changes in the vocal tract that occur in connected speech due to supraglottal articulations.

Irregular vocal fold vibration resulting from a vocal fold pathology may be disordered and erratic. Typically voices with laryngeal pathology demonstrate particular difficulty occurring at voice onset and offset, with an increase in the settling time before the vocal fold vibrations become periodic, although Kelman (1981, cited by Kitzing 1990) found the time before periodicity became stable depended on the vibratory frequency.

SHIMMER is a measure of cycle to cycle variations in amplitude, providing an indication of the overall evenness of this signal

The present study focuses on analysis of data at macro level in relation to Fo (Fx) and vocal fold contact time (QFx), presented graphically and statistically.

6.3.2 *Distribution Histogram*

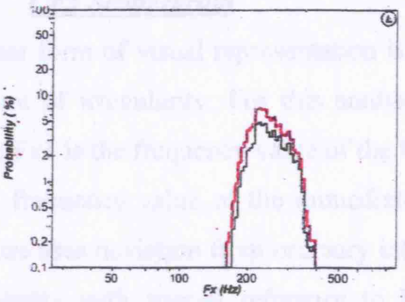
The range and distribution of all the vocal fold frequency values used in a particular speech sample is displayed as a fundamental frequency histogram (DFx). The first-order distribution represents the contents of each of 100 logarithmically equal bins between 10Hz and 1000 Hz divided by the total number of the values and plotted from 30Hz to 1000Hz. (DFx1). DFx2 allocates vocal fold periods to each bin when two successive vocal fold periods correspond to the same bin range and represents the pitched portion of the sample. This is considered a more representative measurement by excluding the influence of laryngeal irregularities (Barry et al. 1990), and on this basis the DFx2 calculations of mean Fx, modal Fx are used for the present study.
The congruence of the two histograms (DFx1 and DFx2) in respect of height and width and configuration of the distribution represents the regularity of the cycles. Period to period irregularity is identified by features of probability, range, modal structure and percentage irregularity and is related to the perceptions of pitch and voice quality.

6.3.3. *__The measurement of Fo irregularity__*

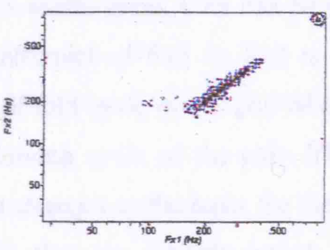
Irregularity is analysed from two perspectives:-

- <u>Temporal</u>; cycle by cycle irregularity resulting from a disturbance of regular periodicity with differences in the timing between adjacent vibrations. Aperiodic vibrations contribute to the perception of a rough vocal quality. (The term rough is used for the purpose of this study to refer to the vocal quality associated with vocal fold irregularity, rather than hoarseness, (referred to by McAllister et al (1996) as illusive and ambiguous), which is typically used to describe an abnormal voice quality characterised by irregularity and breathiness.);
- <u>Closed Quotient</u>; cycle by cycle variations in the duration of the contact phase.

In ELG DFx1 and DFx2 derived from a normal larynx are essentially congruent representing the regularity of the vocal fold vibration. The CFx crossplot shows a well defined diagonal line. (Fourcin 1981.2000).



DFx1 and DFx2 Distributions

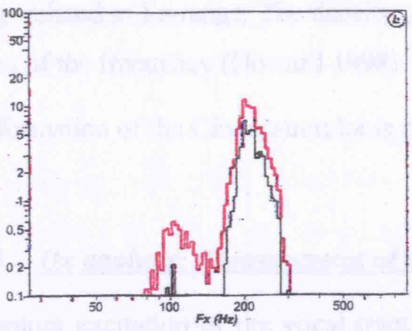


CFx crossplot

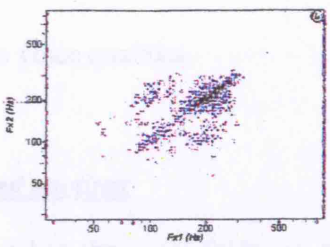
Diagram 12. Distributions and CFx crossplot derived from a normal larynx.

Abberton and Fourcin (2000) describe the histogram derived from the normal larynx as showing a well defined frequency range with a small number of dominant modes.

By comparison irregularity is visually represented in the characteristics of the DFx distributions with DFx1 and DFx2 differing in respect of the features of probability, range, structure and regularity.



DFx1 and DFx2 Distributions



CFx crossplot

Diagram 13. Distributions and CFx crossplot derived from an abnormal larynx

DFx is bi-modal with the spread indicating irregularity. After the irregularities are removed (DFx2) the lower mode is almost completely removed.
The CFx crossplot shows a relatively narrow area of density with the irregularity shown by the scatter around it, extending into the lower frequencies and in the two areas parallel to the diagonal

Fourcin and Ptok (2003) state *"The percept of pitch depends on an auditory inference of regularity of acoustic stimulation."* Irregularity of vocal fold vibration may be related to the perceived degree of vocal roughness. However, from recent work with adult speakers Fourcin and Ptok cite the example of an improvement in vocal quality (spontaneous remission of vocal fold paralysis) generating a greater (albeit slight) irregularity value, (7.4% compared to 6.5% before remission).

6.3.4 *CFx Scattergram*

Another form of visual representation is the CFx scattergram. CFx can be used to give a measure of irregularity. For this analysis a scatterplot of Fx1 vs Fx2 is constructed – where Fx1 is the frequency value of the first vocal fold cycle in any pair of cycles and Fx2 is the frequency value of the immediately following cycle of the pair. The irregularity measure uses deviation from ordinary intonation changes as the basis for the estimation of irregularity with special reference to bin sizes that are directly based on perceptual difference limens. To obtain the irregularity measure the number of cycles in all frequency bins are summed (Total). The number of cycles in all bins that lie on the diagonal of the scatterplot, and all bins that lie immediately above and below the diagonal are then summed (Diag Total). Percentage irregularity is calculated using the following formula: Irregularity =100-((Diag Total/total)*100).
A scatterplot derived from a voice with regular pitch changes will show the concentration of points along a clearly defined X- Y diagonal; variations in the length of the diagonal being related to Fo range. The density of the diagonal indicates the occurrence of pairs of values of the frequency (Howard 1998).

The formation of the CFx scatterplot is related to voice qualities.

6.3.5 *Qx analysis: Measurement of the closed quotient*

Maximum excitation of the vocal tract occurs when the vocal folds are closed. A long contact phase is desirable, particularly to the performing voice because the acoustic energy lost subglottally during the open phase is reduced when the period of vocal fold contact is relatively longer, and the rate of air escape is reduced, enabling phonation to be sustained for a longer period. The length of the closed phase in the vibratory cycle varies according to different voice qualities; modal, breathy or creaky, therefore measurement of the closed phase ratio (CQx) provides further information relating to the perceptual feature of voice quality. Fourcin and Ptok define Qx as *"the ratio of the closed phase interval of vocal fold vibration to Tx, derived from the width of the closure peak of the laryngograph signal between the estimated instant of closure and a point on the opening phase that is 70% down from the peak to peak value of that peak;"*

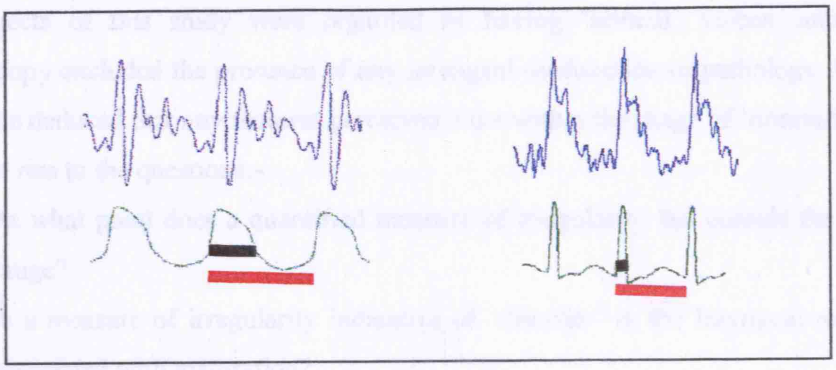


Diagram 14. Measurement of the closed phase. (Source: Fourcin and Ptok (2003))

When the vocal fold mucosal wave is impeded (i.e. by vocal fold pathology) the speed and regularity of the opening and closing phases from cycle to cycle is disturbed. As with the Fx data, comparison of first and second order plots reflects the coherence of measures of this parameter.

Application of this measurement (CQx) is not as established as the use of measures of Fx. Fourcin and Ptok and Stanbridge et al (2005) have demonstrated the clinical relevance of measurement of this parameter with patients with vocal fold paresis, and gastro-oesophageal reflux disease, respectively, and Barlow and Howard (2000, 2005) have investigated the relationship to vocal training.

This provides a representation relating to voice quality based on the duration of the vocal fold contact. The QxFx scattergram displays the contact quotient related to the corresponding Fx value for each cycle. Similar to the DFx1 and DFx 2 a first and second order distribution is presented as well as the average percentage of the cycle the folds are closed.

6.3.5.1. *The relevance of measurement of irregularity*

Measures of Fx irregularity in continuous speech have not been widely studied. In normal speech regular vocal fold vibration gives rise to a perception of pitch. Irregular vocal fold vibration disturbs this percept. It may be expected that irregularity would result from the instability associated with maturation and measurement of percentage irregularity could be a useful index warranting further investigation.

However, the extent to which vocal fold vibration varies and the point at which this is considered abnormal is more difficult to define.

The subjects of this study were regarded as having 'normal' voices, and indirect laryngoscopy excluded the presence of any laryngeal dysfunction or pathology. From this it might be deduced that any features perceived were within the range of 'normality'.

This gave rise to the questions:-

- At what point does a quantified measure of irregularity fall outside the 'normal' range?
- Is a measure of irregularity indicative of 'disorder' in the laryngeal mechanism associated with maturation?

Baken (1990) describes the phonatory system, including the supraglottal vocal tract, larynx and subglottal air supply, as *"an oscillator regulated by a very complex set of interconnected control mechanisms"* and suggests that irregularity manifest in the output may be "a surface indication of this complexity. And crucially that irregularity can be *"considered to be adaptive"* Measures of irregularity therefore identify the way in which one of the components of the system functions but do not provide explanations of why these events are occurring.

The relationship between what can be heard and what can be measured is fundamental in speech pathology. With the advent of complex and sophisticated measuring techniques disturbances of speech production can be detected that cannot be heard but which may be useful to differential diagnosis, as an indication of emergent pathology or disorders. (Leff and Abberton (1981), Weismer (1999), or an an indicator of voice change associated with maturation.

Baken (1990) comments on the importance of irregularity (perturbation) as a characteristic component of the speech signal which has particularly attracted interest in the study of voice production and voice disorders for two reasons, (i) to further knowledge of the laryngeal and vocal tract mechanisms and (ii) because a disruption of regularity can be the consequence of laryngeal pathology, therefore irregularity may be related to the severity of vocal dysfunction. Rontal et al (1983, cited by Fitch 1990) reported identification of patients with pathological conditions from measurement percentage of Fo perturbation to have a high degree of accuracy. Lieberman (1963 cited by Brown et al 1989) defined perturbation in vocal pitch as small cycle to cycle variations in fundamental frequency and reported that excessive jitter could be detected in people subsequently diagnosed with laryngeal cancer, even before hoarseness was apparent.

The relationship between the perceptual acoustic features and the histogram characteristics was studied by Leff and Abberton (1981) in eight patients with schizophrenia and eight patients with depression to investigate whether the monotonous voice quality which characterises both conditions can be distinguished. Measures of kurtosis were derived from the Fo distribution and demonstrated that this measure did not identify a diagnostic distinction, but did demonstrate differences between schizophrenic patients with and without an emotional blunting affect.

6.4 *Perceptual evaluation of voice quality*

Systematic perceptual evaluation provides structured description of the auditory perceptual features of voice quality, (Dejonckere et al (1993), Carding et al (2001), Bhuta et al (2004)). It is important to the differentiation of the auditory features of voice disorders, and for clinical management (Orr et al (2002), Granqvist, (2003)), but the specific use of perceptual rating in terms of the parameters evaluated, the materials and the rating systems used, is problematic. Despite numerous studies (particularly the work of Kreiman and co-researchers (1990.1992.1993), de Krom (1994), and more recently Webb et al (2004), reliable rating of voice remains elusive, endorsing the view of Jensen (1966, cited by Kreiman et al (1993)) that *"the assumption that the perceptual characteristics of a person's voice provide sufficient information for a reliable description of voice deviation and its severity appears to be hazardous."*

A review of the literature reveals the numerous factors which influence perceptual judgements and highlights the deficiencies of the procedures used.

Current studies of perceptual rating schemes relate to the adult speaking voice, with the focus on pathological voice, (perceptual evaluation is also relevant to forensic work, and distinguishing the perceptual characteristics of a voice underlies voice imitation (Zetterholm 2002)); however, the aspects of perceptual evaluation which are open to criticism, and factors which affect perceptual judgements, apply equally to work with children and will be discussed further.

6.4.1 *Identifying normal' voice*

The explanation by Fex (1992) of perceptual evaluation as a method of *"making a comparison between a (perhaps unspecified) number of qualities that the listener can hear in the speaker's voice and the listener's own opinion about how these different qualities should sound in the normal voice"* highlights the subjectivity of the process.

Moore (1971, cited by Aronson 1985) suggests *"It is obvious that there is no single sound that can be called 'normal voice', instead there are children's voices, girls' voices, boys' voices, women's voices, men's voices, voices of the aged, and so on. In each of these types of voice, both normal and abnormal can be recognised. The location of the threshold that separates the one from the other is judged by each listener on the basis of his cultural standards, education, environment, vocal training and similar factors. This observation should alert the speech clinician to the fact that voice disorders are culturally based and socially determined"*.

A concept of normal voice is essentially learned (Moore 1971, cited by Eskenazi et al (1990)), and further influenced by experience (Papcun et al. (1989), Kreiman et al (1992)); the effect of language characteristics, sociological factors and regional accents is therefore relevant, (Montague Jr. and Hollien (1973);Singh and Murry (1978); Ringel and Chodzko-Zayko (1987); Huntley et al (1987); Sodersten and Lindestad (1990)). Eskenazi et al (1990) present a definition of normal voice as *"a voice with no apparent pathology (either functional or organic) and no unusual voice characteristics or habits."* This definition is useful to the present study since none of the subjects were considered to have any functional, organic or perceptual abnormality. Wilson (1987) and Speciale and Cimino (2000) refer to "a pleasing quality", features of resonance, loudness and pitch *"suitable for age, size and sex".*, also referred to in the Royal College of Speech and Language Therapists' definition of dysphonia, (1998).

6.4.1.1 *Factors influencing perceptual judgements*

Kreiman et al (1990.1992) found experience influenced the strategies applied by listeners in evaluating voice quality, and the consistency of the judgements. The paucity of research into how and why listeners judge voice qualities differently is noted, with the focus of studies of voice perception directed at the stimulus characteristics rather than listener behaviour, and Kreiman et al ((1990),who have extensively researched this subject) suggest the research designs of studies may not be sensitive enough to demonstrate differences in the perceptual strategies applied by listeners. For example, Huntley et al (1987) and Neiman and Applegate (1990) – who also cited Hollein and Tolhurst (1978) - found estimates of age are influenced by the age of the listener.

Perceptual evaluation is a skill that evolves from a knowledge base; the level of skill, how it is acquired, developed and maintained are important so that they are not reinforcing listener bias, either of subject groups, or diagnostic categories by focusing on features that support a hypothesis. (Montague and Hollien (1973) presented the sample recordings of children with Down's syndrome played backwards to prevent any *"prejudicial bias"* (arguably revealing a preconception), resulting from the *"disordered articulation"* of the subjects.)

- Kreiman et al (1990) found that naïve listeners agreed on the relative importance of different aspects of voice quality, whereas experts were found to vary the strategies according to the characteristics of paired voice samples, resulting in less rather than more agreement.
- Kreiman (1993) did not find a *"consistent relationship between listeners' background and levels of interrater reliability".*

- McAllister et al (1996) reported a high correlation between the ratings of children's voices by the experts and the children's teachers.

Bassich and Ludlow (1986) consider significant clinical experience is required to obtain reliable ratings of voice and the findings of a study by Bergan et al (2004) suggest a relationship between training and perceptions of certain parameters.
The effect of training is particularly relevant where it is a pre-requisite for use of a rating scheme, as applies to the Vocal Profile Analysis Scheme, (V.P.A.: Laver et al (1991) (Nieuwenhuis (1986). Kreiman et al (1990) question the influence of structured rating tasks on listener behaviour. Although Kreiman (1993) refers to task-specific listener training, very little information regarding training is given in papers reporting on the perceptual evaluation element of studies.

6.4.1.2 ***Reliability of perceptual evaluation***

Bergan et al (2004) state *"if diagnosis and therapy of vocal pathologies is to improve, it is important to determine the reliability and validity of voice quality assessment."*

It follows from the concept of an internal reference mechanism that evolves from exposure to and experiences of voices stored to memory, that these internal references will vary between listeners and will influence perceptions and judgements, as well as methodological factors. The way in which stimuli are presented (Kreiman et al 1993); the proportion of samples of normal voice qualities presented and the relative severity of abnormal voice samples in a stimulus set (Kreiman et al (1993); Rabinov et al (1995); Gerratt et al (1993)) and the sensitivity of the rating scale to chance agreement (Kearns and Simmons (1988); Granqvist (2003); Wutys et al (1999)), led Kreiman et al (1993) to conclude that no one factor *"does, or does not contribute to rating reliability."*

There is scant reference in current literature to the speaker's perceptions of voice quality. Carding et al (2001) refer to the role of perceptual evaluation in communicating with patients and Greene and Mathieson (2001) suggest the use of self-rating. A hindrance in this respect is the diverse and ambiguous terminology,

Although therapists and patients may have comparable views of the effects of dysphonia (Scott et al 1997), Sellars and Dunnet (2002) suggest the level of agreement between therapists and patients regarding aspects of most concern to be rather poor, indicating a need for an evaluation system that includes the parameters identified as relevant to patients, with meaningful descriptions. This would also have application as a screening tool to assess for features indicative of potential problems referred to by Orr et al (2002) as *"something elusive"* in the absence of any visible organic problem. Rosen and Murry (2000) refer to singers sensitivity to small changes in their voices and comment that the questions in the Voice Handicap Index in Singers (VHI), developed to assess patients' perceptions of their voice disorder (Jacobsen et al 1997) focus on the singing rather than the speaking voice.

6.4.2 ***Terminology***

Fex (1992) wrote *"Terminology is thus a serious problem in serious need of a solution."*

Ambiguity in the use of terminology results from two problems:-

- Difficulty determining what the choice of a word means in relation to the vocal presentation.
- Establishing the use of terms that mean the same thing to everyone involved.

6.4.3 *Selection of materials for perceptual evaluation*

The purpose of the perceptual analysis determines the choice of rating tool, and variables such as the sample used, the listeners, and the listening procedure.

Opinions regarding the choice of materials are, (i) that connected speech is preferable as it is more representative of the conversational speaking voice, Hammarberg et al (1980); Klingholz, (1990); Fex, (1992)), and (ii) that vowel-type stimuli are adequate (De Krom, 1994).

Kreiman et al (1993) comments on the deficiencies in the literature reviewed in terms of a *"clear theoretical approach"* to the processes of perceptual evaluation and there is surprisingly limited reference to the use of materials, although this is highly pertinent to the parameters evaluated; eg. Moran and Gilbert (1984) found that judgements based on the stable portion of a sustained vowel may underestimate pathological change.

6.4.4 *Listening Procedures*

Most studies use audio recordings (eg. Neiman and Applegate (1990); Gerratt et al (1993); Kreiman et al, (1990,1992,1993). Clinicians who rate a patient's voice when they are in the clinic have to consider whether other factors, (such as the individual's presentation and overall manner of communication), are influencing judgements. Listening procedures should also take account of fatigue which may negatively affect judgements (Granqvist 2003), and other aspects that may influence evaluation.

Kreiman et al (1990) suggest that *"apart from Fo, a set of parameters that is common to different populations of listeners judging the same voices may not exist."*, echoing the view of Murry and Singh (1980) that *"...besides the Fo/pitch measure, there is no common set of acoustic parameters for judging voices applicable to both sexes and phonation conditions (i.e. for both vowel and phrase stimuli).",* reiterated by Bhuta et al (2004):- *"voice is a multidimensional function. No measure can accurately evaluate all of its aspects."*

The term perceptual evaluation or perceptual assessment is accepted as standard by the International Association of Logopedics and Phoniatrics Voice Committee. However, there is no standard rating procedure and format, with variations of design and the criteria applied for the selection of parameters. The choice of the scale used should be based on the detail required appropriate to the application of the rating and taking account of the experience of the user.

The Vocal Profile Analysis Scheme (VPA) (Laver et al 1981) was developed from the premise that idiosyncratic laryngeal and supralaryngeal features determine the characteristics of an individual's voice quality.

The Buffalo III (BVP Wilson 1987) includes features which are not directly related to vocal sound and function.

The GRBAS (Hirano 1981) used in the present study, is focused on the laryngeal components

6.4.5 *GRBAS Scale*

An expert panel of Speech and Language Therapists commissioned by the British Voice Association in 1998 to produce a position document on formal perceptual evaluation of voice quality in the U.K., recommended the GRBAS Scale (Isshiki et al (1969); Hirano (1981)) as the *"absolute minimum standard of vocal perceptual evaluation skills for all practising UK speech and language therapists."* (Carding et al 2001). The scale was developed by Hirano (1981) from the work by Isshiki et al (1969) identifying the dimensions of perceived hoarseness as rough, breathy, asthenic and degree, in a system of rating vocal quality using five well-defined terms.

G (Grade)	Overall grade of hoarseness or abnormality.
R (Rough)	The impression of the vocal fold vibration regularity
B (Breathy)	The perceptual effect of glottal air leakage/turbulence
A (Asthenic)	Weakness / lack of power/lack of higher harmonics
S (Strained)	The impression of hyperfunction/excess effort.

Each parameter is rated on a four point ordinal scale; 0 denotes normal (grade) or none of the quality present; one denotes slight; two – moderate, and 3 – severe. It does not assess pitch and loudness, (except in relation to the asthenic quality).

Although dysphonia is not the topic of this study it is worth noting the conclusion of Dejonckere et al (1993) that the profiles derived from GRBAS for primarily organic voice disorders differ from those for primarily functional voice disorders, indicative of a useful level of sensitivity.

CHAPTER VII PREVIOUS WORK ON CHILD VOICE

7 Introduction

Because of the complexity of the subject, reference is inevitably made in previous and following chapters to other studies relating to the topics discussed. Many of the references cited are based on studies of adults because of the limited amount of material specific to children's voice. Van Oordt and Drost (1963) reported that a review of research of the vocal range of the child *"suggests that interest in the child voice has been almost entirely aesthetic;* however, there is now more interest in this field compared to the previous perception that it is relatively unimportant, White and Sundberg (2000). White (2000) suggests children's limited co-operation, and difficulties in obtaining accurate measurements are significant amongst reasons for the limited data on children's normal voice production, as well as a misconception that voice problems in children resolve with maturation.

Stathopoulos, (2000) referring to the anatomical, physiological, acoustic, aerodynamic and respiratory differences that demonstrate children are not adults on a small scale, and to Thelen's model (1991) that *"a biological system will prefer certain behaviours because of its own structure, the environment and the task",* argues the need for *"an account of how children function at different ages in various contexts".* The choice of materials used in studies of voice also has to take account of the maturation of the motor speech system, and, if reading materials are use, the child's literacy skills.

Hasek et al (1980) reported that all of the 24 studies of children reviewed, (male and female, age 5–10 years), involved a single phonatory task only. 18 of the studies involved reading or sentence repetition; 3 sustained vowels; 2 spontaneous speech and one a picture stimulus.

Given the numerous variable and complex interactions, it becomes apparent why studies of child voice are limited in number and scope.

This chapter provides an overview of previous work on childrens' voice. Reference is made to some early work because many of these researchers created such a strong foundation and the observations made are still relevant to current research.

7.1 An overview of early work (1940 – 1970)

In 1940 interest provoked by the voice 'breaks' which characterised the adolescent male voice, prompted Curry to *"investigate objectively the pitch characteristics of the male voice during the pre-adolescent, adolescent and post-adolescent stages of development."*. Curry reported that no previous comparative studies of this feature had been found in the literature of speech, psychology, music or medicine, although reference is made to the findings of Jerome (1937) of a mean chronological age of 166.75 months (13.9years) (range 62 months / 5.1years) for voice change.

The subjects fell into three categories:-

(i) pre-adolescent (not yet reaching voice change) age 10years

(ii) adolescent (undergoing voice change) age 14 years

(iii) post-adolescent (undergone voice change) age 18 years

The gap between groups (i) and (ii), spanning four years at a crucial stage of their development is notable. The criteria for subject selection were physical size; chronological age; reading comprehension; speaking ability; intelligence.

Age (yrs)	**Height**		**Weight (lbs)**		**Chronological Age**		**Reading Comprehension**		**I.Q.**	
	Range	Mean	Range	Mean	Range (mnths)	Mean	Range	Mean	Range	Mean
10	52 - 55	53.5	62 - 69	66.3	118 - 122	120.3	3.5-4.4 reading grades	3.9	97 - 108	101
14	59 - 61	60.2	97 - 110	102.2	167 - 172	169.8	7.7 - 8.8	8.3	97 - 110	103.7
18	66 - 70	68.2	131 - 148	139.3	213 - 222	216.7	*			

(* Mean composite score and mean reading comprehension; State University of Iowa Qualifying Examinations, 52nd percentile)

Table 8 Measures for criteria used in an early study of child voice, (Curry 1940)

One objective of this study was to examine intensively any *"breaks"* found in the voices, referred to as chaotic periods *"between the low and high frequencies reached by the voice ...during which frequency cannot be measured with certainty."* These were identified in the two youngest age groups, and were characterised by an abrupt change in the duration of one cycle to the next, noted to occur within a narrow frequency range. In the 10-year-old subjects the upward breaks all occurred within a three tone range and at a higher frequency than those observed in the 14-year-old subjects.

Two points were identified; (1) that in 10-year-old and 14-year-old subjects the breaks typically occurred within one octave range below the median pitch, (although the 10-year

–old subjects were considered as not yet reaching voice change), and (2) that the average extent of breaks was also approximately one octave.

Curry considered interpretation of the analysis speculative but compares the phenomenon to that created by the increase of air pressure in an overblown pipe, and may be related to changes in breath pressure.

In 1949 Fairbanks et al reported on acoustical studies of vocal pitch in seven- and eight-year-old girls' (Fairbanks, Herbert and Hammond), and in seven- and eight-year-old boys, (Fairbanks, Wiley and Lassman). The study of girls was thought to be the first presentation of acoustical data on the vocal pitch of girls, and also tested the hypothesis that voice breaks are not sex-linked.

Previous work by Fairbanks (1940. 1942) and by Pronovost (1942) provided a reference for the extent of the lowering in pitch level between infancy and adulthood in males, with the later study aiming to provide two additional plotting points on a curve of changes in pitch level as a function of age.

Subjects for both studies were selected at random (except in respect of sex and age) and were able to read a specifically constructed passage appropriate for second grade children. Frequency measurements were derived from an oscillographic device. The most important and unexpected finding of the study of the girls' voices was the manifestation of voice breaks, from which the researchers inferred that *"voice breaks are non-sex-linked phenomena of childhood which typically disappear prior to establishment of adult vocal habits."*

Mean pitch values are compared to the median values reported by Curry (1940); however, the relevance of this data is limited by the relatively crude systems of pitch extraction

Researcher	Speaker Age (yrs)	Material	Mean occurrence of pitch breaks
Fairbanks	7	52 word passage	3.8
	8		3.7
Curry	10	55 word passage	3.3
	14		4.2

Table 9 Occurrence of pitch breaks found in early studies.

	Age - Girls		Age - Boys	
	7 years	8 years	7 years	8 years
Mean age in months	84	95	84	96
Age Range in months	82-86	93-97	82-86	94-97
Mean height in inches	50	53	49	51
Height range in inches	45-64	50-58	44-57	47-57
Mean weight in pounds	56	60	56	61
Weight range in pounds	40-134	46-75	42-82	50-81
Pitch level	281	288	294	297
Tones above 16.35cps	24.6	24.8	25	25.1
Pitch Range	10.3	10	9.8	9.7
No. of voice breaks	3.1	3.4	3.8	3.7

- \- zero reference frequency. 16.35 = C0; Middle C = C4; 25.0 = D4 (1 tone above Middle C)

Table 10 Biometric and voice measures of 7- and 8-year old girls and boys (Fairbanks 1949)

Van Oordt and Drost (1963), studied 126 children in two groups, (45 age 0 –5 years; 81 age 6–16 years). Because of the difficulty of compliance the young children were recorded when crying spontaneously to identify the lowest tone, the highest 'pure tone' and the highest 'impure tone'; the authors acknowledge the limitation of this test. The older children were instructed to start from an arbitrary tone in chest register and to first ascend, then descend at chromatic intervals to identify the highest and lowest registered physiological tones and the physiological frequency range. The frequency of a reading and speaking voice was derived from a reading task and conversation respectively. The results were plotted in octaves against age:-

Group A (0–5 years) Physiological range of majority of subjects:- 2½ – 3 octaves
Group B (6–16 years) Physiological range of 23% of subjects:- wider than 3 octaves

From comparison of the physiological frequency range and the musical frequency range, (extracted from the physiological range by perceptual evaluation), the authors concluded that while the physiological voice range at age 10 years is comparable to the range at 6 years, the musical frequency range increases and suggest that *"Differences in the amount of exercise will result in wide differences in the development of the musical voice range in a given age group."*

Whilst the findings are based on essentially subjective judgements, the findings are important, with the conclusion that the relationship between the speaking and singing voice is not as close as previously thought and significantly that the production of speaking and singing tones differ.

In 1970 Weinberg and Zlatin (USA) studied 66 children, aged from 5 years to 6 years 10 months (mean 6years), with normal hearing for speech, speech and intelligence as a control group in a study of the mean speaking Fo of 27 children (age 5 years 1 month, to 6 years 1 month, mean 5 years 1 month) with trisomy-21 type Down's syndrome.

Speech samples were elicited by presentation of a range of materials (questions, colour pictures and puzzles) and a 30 second sample of each recording analysed by use of a Fundamental Frequency Indicator (FFI).

Control Group	Mean Age	Mean Height (inches)	Weight	Mean SFF (Hz)	Range (Hz)	Semitone Range
Males 5 years	67.73	46.58	44.56	252.4	217.2 - 292.7	5.16
Females 5 years	65.66	45.92	44.88	247.6	211.9 - 295.2	5.74
Males 6 years	78.28	49.03	56.64	247.3	204.1 - 274.4	5.12
Females 6 years	76.63	48.39	49.31	247	217.7 - 274.1	3.98

Table 11 Biometric and voice measures for 5- and 6-year old boys and girls. (Weinberg and Zlatin (1970)

The aim of this study was to evaluate the clinical observation that a characteristic feature of children with Down's syndrome is a low voice Fo.

This was not supported by the findings that the speaking Fo of the experimental group was significantly higher than that of the controls, other than the 6-year-old males. This study was valuable in two particular respects:-

- Comparisons of data on height and weight demonstrated that the children with Down's syndrome were on average comparable to 4-year-old children in relation to height and to 5-year-old children in relation to weight. From this it is inferred that the higher Fo correlates to the smaller larynx size assumed in smaller children.
- The data on voice Fo in the control group provided the first analysis of this feature in normal five- and six-year-old children. Comparison of this data with that from the studies of 7- and 8-year-old males (Fairbanks, Wiley and Lassman 1949) and 7- and 8-year-old females (Fairbanks, Herbert and Hammond 1949) shows a lower mean speaking Fo for the normal 5- and 6-year old children which the researchers attribute to a lower level of speaking Fo for children than for those studied in the 1930s and 1940s, and the use of spontaneous speech rather than oral reading to elicit speech samples.

None of these studies are based on data derived from U.K. subjects.

7.2 Longitudinal Studies

Longitudinal studies have been reported by,. Tosi et al (1976)); Bennett (1983), Sorensen (1989), Hollien et al. (1994), Whiteside et al (2002), and Barlow and Howard (2002 and 2005); Williams et al (2005) have reported initial findings of a study of choristers' singing and vocal behaviours.

Tosi et al. studied 33 males aged 9.2years – 18.1years from the Children's Hospital of Buenos Aires. Recordings were made at intervals of approximately 4.5months of five sustained vowels and a short sentence.

The Fo was measured from spectrograms at 100msec intervals; mean and standard deviation were calculated from a 'melody curve'. Subjects were grouped according to a classification devised by Marshall and Tanner (Variations in the patterns of pubertal changes in boys. 1970), the criterion for the groups 1 – V including percentage of plasma testoterone, urinary 17-ketosteroids, sweat pH and size of genitalia; a further group 0 was used by the researcher (Bianculli) referred to as a "propuber".

Comparisons of the frequencies of subjects at the same stage of maturation demonstrated a close correlation with the maximum rate of change, (as well as of weight and height), occurring at 13.3years in this subject group, (Argentine urban children of middle class European extraction).It might be assumed that although the subjects were selected from a hospital population with no significant relevant medical conditions it is questionable whether, under such circumstances, they can be considered representative of a normal population. Details of the material recorded, specifically the sentence length and how it was elicited would enhance the information.

Bennett (1983) questions *"whether the mean fos for different ages can be compared validly"*, especially in the context of differences in methodology used by researchers. Data was collected on 15 boys and 10 girls age 7/8 – 11 years at twelve-month intervals over a three year period; a twelve syllable declarative sentence spoken first by the researcher was recorded and the frequencies calculated. The key features identified were:-

- A generalised lowering of Fo over the three year period
- A consistent lowering in mean Fo was not identified in data for individuals
- Age related changes occurred and were comparable for both boys and girls

- The mean Fo of the voices of the boys and 10 and 11 were above 195Hz with no evidence of maturational change

Bennett concluded that these findings demonstrated that age-related changes can be detected over a one year period from year to year comparisons of group data based on longitudinal observations.
However, it should be noted that the average decrease in mean Fo per twelve month interval was merely 12 Hz (SD $\pm$ 8Hz) and the group difference over the three year period was only 18Hz(1.4 semitones (S/T))-boys, and 14Hz (1.0 S/T) – girls. Reference to the variation in pattern of change revealed between individuals highlights the significance of all the variables that affect vocal function and the limited relevance of group data based on one factor.
Sorenson (1989) investigated a total of 30 children, (3male and 3 female at each age of 6.7.8.9 and 10yrs) to assess the Fo characteristics on a range of tasks; sustained vowel, spontaneous speech and reading. Subjects were screened to exclude those with any laryngeal or respiratory history, language and / or articulation problems, or hearing acuity less than 25db at 500, 1000 and 2000Hz. The tasks were:-
Oral reading of two pages of a first grade level text.
Picture stimulus to elicit 30 seconds of spontaneous speech
Vowels, sustained as steadily as possible for 5 seconds.

All tasks were practised and the researcher reported that demonstration and practice of the vowels was essential. A three second segment was used from the mid portion of the most stable production of each vowel, identified from intensity x time waveforms and by listening to samples.

The measures of Fo derived by use of an automatic Fo analysis programme showed there was no significant difference between the average Fo of male and female children in this group, consistent with the findings of other studies (Fairbanks et al (1949), Van Oordt and Drost (1963)); however, a second analysis did demonstrate some differences. Sorensen reports that *"the male fundamental frequency lowers in the age range 6 to 7 years, then remains relatively stable."* This finding is not evident from the presentation of data which shows an increase in the mean Fo in boys of 25.76Hz (1.58 S/T).
The highest Fo values were derived from vowels, the lowest Fo values were found on spontaneous speech with oral reading higher than spontaneous speech attributed to high laryngeal tension.

7.3 Studies related to cultural aspects

Morris (1997) points out that the subjects of most published studies of speaking Fo (SFF) (of male children) are white boys.

Bowen (1997) undertook a cross-sectional study on the effects of ageing on the human voice. The three groups of subjects (ages under 11years; 35-5years and over 70years) came from six different ethnic groups living in the UK; (Bangladeshi, 2; Irish, 2; Italian, 2; British, 4; Ghanaian,1; Kashmiri,1), however the data was presented according to age and gender with no cultural or linguistic comparisons.

Wheat and Hudson (1988) reported a modal speaking Fo (SFF) of 220Hz in six-year-old African-American boys, and Hollien and Malcik (1962) reported a mean speaking Fo of 210Hz in ten-year-old African-American boys. No longitudinal or cross-sectional studies were available.

From the finding that the SFF of six-year-old African-American boys were lower than those of six-year-old white American boys Wheat and Hudson (1988) suggested *"it may be inappropriate to make judgments about vocal characteristics of Blacks using normative SFF date collected on whites."* The significance of culturally derived differences in SFF is pertinent to a multi-cultural society.

Morris' study (1997) involved 30 boys at each of three age levels between 8–10 years, in two racial groups, (i.e. 6 groups of 15 boys). Analysis of recordings of the second reading of a passage, and a picture description, provided the SFF (in Hz), the distribution and the pitch sigma, ('pitch sigma' is the term used by the researcher; it is not defined but appears to refer to the Fo range).

Although there were no significant differences in modal SFF between African-American and white-American boys on either task, nor were there significant age-related differences in either racial group, differences identified in pitch sigma were considered significant:-

- the larger pitch sigmas in 10-year-old African-American boys, compared to the 8-year-old and 9-year-old was not identified in white American boys.
- 9-year-old and 10-year-old African American boys demonstrated larger pitch sigmas than the white-American boys of this age in reading.
- the 10-year-old African-American boys demonstrated larger pitch sigmas in speech than the 10-year-old white boys.

The SFF levels reported were considered comparable to those reported in other studies, except for the values for 8-year-old white-American boys (Reading 220Hz. Speech 213Hz) compared to those reported by Bennett (1983) of 234Hz. This finding led the author to suggest that the SFF levels of boys from these two racial groups are similar and that normative data from white-American subjects can be generalised to this age range, and that *"no significant developmental changes occur laryngeally to affect fundamental frequency from age 8 to age 10."*

Speculation that the wider pitch sigmas particularly in the 10-year-old boys were the result of pitch breaks was not supported by perceptual evaluation of the recordings. The author also questions whether the differences found in pitch sigma values between the two racial groups is related to an *"increasing approximation of the adult male speech model within each speech community."* Studies of African-American males (cited Hudson and Holbrook. 1981.1982; Weller et al 1981) show the use of lower average SFF levels than found in white men.

Morris' suggestion that lower SFF levels may be a pubertal or postpubertal development reflecting the influence of the speech model within the speech community is important.

7.4 Studies of acoustic characteristics in relation to age and sex

Notable studies of acoustic characteristics as a function of sex and age have been undertaken by Hasek et al (1980), and Whiteside and Hodgson (1999 and 2000). As previously referred to,

Hasek et al reviewed studies of average Fo in children and commented that the diversity of methodology and lack of comparative data for pre-adolescent children limited the scope to draw conclusions – a theme echoed by Whiteside et al (1999). Hasek et al. used voice samples obtained for a study by Brown et al (1978) of recordings of sustained phonation of the vowel [a] collected from fifteen boys and fifteen girls from 5years to 10 years, (total 180).

Pertinent factors of the methodology are (i) measures of Fo were derived from one vowel (/a/) phonated in a normal speaking voice, (intended to focus on sex and age comparisons) and (ii) that the children were given training and practice trials *"as needed"*.

These researchers reported:-

- A significant difference between the average Fo of male and female children age 5 years–10 years.
- Significant differences were also found between the average Fo of children age 5years and 6 years compared to values derived between ages 6years and 9years.
- The effect of age on Fo was found to be significant for males but not for females, and was considered to indicate the emergence of a significant difference of the average Fo in male and female preadolescents by the age of 7years or 8years because of the lowering Fo in male children beginning at about 7 years.

Information given regarding the subjects is limited. It is not apparent what criteria were applied and specifically whether the children were screened in respect of hearing, laryngeal and respiratory health.

Age (yrs)	Male			Female		
		Range			Range	
	Fo (Hz)	Hz	Semitone	Fo (Hz)	Hz	Semitone
5	247.5	186-313	9	257.7	202-306	7.2
6	262.5	228-332	6.5	254.3	210-313	6.9
7	234.2	199-264	4.8	261.7	195-303	7.6
8	235.6	195-313	8.1	264	215-306	6.1
9	230.4	211-254	3.2	246.7	210-281	5
10	228.9	173-293	9.1	253.7	234-303	4.4

Table 12 Fo measures for children 5 -10years (Hasek et al 1980)

Age Interval	Boys		Girls	
	Difference in frequency values			
	Hz	Semitones	Hz	Semitones
5yrs - 6yrs	15*	1	3.4	0.2
6yrs - 7yrs	28.3	1.9	7.4*	0.5
7yrs -8yrs	1.4*	0.1	2.3*	0.1
8yrs-9yrs	5.2	0.3	17.3	1.1
9yrs-10yrs	1.5	0.1	7*	0.5

- Denotes the value is higher than that for the preceding year

Table 13 Year to year comparison of Fo values for children age 5-10years (Hasek et al 1980)

The tables above show the data presented by Hasek et al, and the differences in Hz and semitones from year to year. The overall difference between the ages of 5years and 10years is 18.6Hz (1.35 S/T) for boys, and 4Hz (0.27 S/T) for girls.

Whereas for the boys both the lowest and highest values of the range drop by a similar amount (lowest 13Hz (1.25 S/T); highest 20Hz (1.14 S/T), the drop in the lowest value for girls is much greater than the drop in the high value, (low value 32Hz (2.54 S/T); high value 3Hz (0.17 S/T), indicating that the girls retain the higher frequencies..
The researchers concluded that *"the male/female difference was directly attributable to a decline in Fo for male children only, beginning around age seven."*

Whiteside et al (1999) refer to results from other studies and comment on the inconsistency of findings in relation to Fo change as a function of age and sex in the age group 3–10 years, and suggest the extent of individual/group variability in Fo as a function of age may be indicative of the child's control of the system associated with maturation of the central nervous system.

Recordings were made of twenty children from a primary school in Tyneside (N.E.England) Target phrases (article, adjective, noun) elicited using picture cards were recorded and analysed on a Kay Computerised Speech Lab. The vowel in the final nouns (bar; jar; car) was also analysed for formant frequency and formant bandwidth.

The results were reported to show a *"significant age-by-sex interaction"*. A steady declined in Fo was reported in girls between the ages of 6years and 10years, with a more marked decrease identified in the boys between the ages of 8years and 10years. Although this was considered to be consistent with the findings of Hasek et al (1980) it is not reflected in the values reported, with the mean Fo of girls age 10years only 4Hz below that of the girls age 5yrs, (as previously referred to).

The researchers suggest the Fo data indicates a substantial decrease in Fo in boys beginning at around 8 years, but question the relative influence of physiological, social and cultural factors – particularly the acquisition of intonation patterns and propose that *"the development of Fo in children is not only determined by physical growth and changes in the vocal organs but are also a product of the sociolinguistic factors that may be operating in a specific speech community."*, and suggest that interpretation of age related decreases in Fo SD data should take account of the intonation characteristics associated with accent, dialect or language of the subjects. However, the materials used may have limited the potential to identify the influence of these factors.

Linders et al (1995) used ELG to study the influence of gender, age and height on the Fo and jitter in the voices of 63 girls and 29 boys age 7years – 15years; (notwithstanding the upper age of the boys none was considered to be in the mutation or pre-mutation phase of maturation).

The researchers experienced technical problems with the electrodes and consequently 21 recordings could not be analysed.

	Median Fo (Hz)	Range	
		Hz	Semitones
Girls	244	182 - 331	10
Boys	250	205 - 293	6.2

Table 14 Measures of voice Fo and range reported by Linders et al (1995)

Both Fo values and jitter ratios were found to be significantly negatively related to height but not to age or gender. These researchers reported that neither voice parameter depended on gender and that although Fo decreased with age and height, height was the most important factor. The average Fo values found were consistent with available data; however Linders et al comment that *"acceptable limits are very large."*

These findings are remarkable for a subject group which includes boys to the age of 15 years.

Brief reference will be made to a paper by Cheyne et al (1999) reporting the results of a study from which *"Normative EGG data were established for children aged 3 to 16 years."* Recordings were made of 164 children attending a paediatric otolaryngology clinic, (*"for reasons unrelated to any voice disorder"),* uttering a vowel (/a/) for three seconds; three times in a *"comfortable or conversational voice",* three times in a loud voice.

The results are presented as a series of charts, which appear to be void of specific data; however the authors report that *"no significant dependence on age"* was found from analysis of jitter, open quotient, closing quotient, and opening quotient.

7.5 Studies of hoarseness in children

Kauffman et al (1992) reported that chronic hoarseness is frequently identified in children, although this conclusion was based on the evidence of vocal pathologies identified by laryngoscopy in children attending a specialist phoniatric out patient clinic without reference to the incidence of the child population the subject group was derived from.

Silverman (1975) reported an incidence of 23.4% chronic hoarseness identified by screening of children from a Hebrew school, and suggested that this finding was indicative of chronic hoarseness in a large number of school-age children. This did not take account of any specific cultural and educational characteristics of the subject group.

Sederholm (1996) investigated hoarseness, its occurrence and related factors, in 10- year-old children and found this feature in 14% (of a group of 205children) and chronic hoarseness in 6% (the prevalence in children from densely populated areas was significantly higher at 21%). 12% of the children investigated (all boys) were found to have vocal nodules and 44% incomplete glottal closure.

McAllister et al (1996) explored problems associated with analysis of relations between Fo perturbation and perceived hoarseness and its predictors, (breathiness, hyperfunction and roughness - found to account for 91% of hoarseness). The authors referred to previous research showing vocal fry did not contribute significantly to the parameter of hoarseness. Six 10-year-old subjects, (2 with chronic hoarseness, 1 with glottal chink, 1 with mutational voice and 2 without any abnormality) were assessed speaking a short text of eight simple sentences, and a short phrase, (it is not clear how this was elicited). The researchers reported perturbation values higher for continuous speech than for sustained vowels and that there was no clear difference between adults and children for Fo perturbation in continuous speech. The correlation between perturbation measures and perceived hoarseness was considered negligible, and it is suggested high perturbation measures reflected voice characteristics not related to hoarseness. The higher Fo of children was considered a possible relevant factor.

These researchers concluded that their analysis appeared to expose the limitation of the perturbation concept as a correlate of hoarseness, *"at least in its present form"*, and advocate the use of sustained vowels for future analysis of hoarseness.

7..6 Studies of voice change in relation to biological maturation

A leading authority on adolescent voice is Dr Mette Pedersen in Copenhagen, who, with co-researchers, has studied the characteristics of voice change in relation to biological maturation. (1977-1993).

Pedersen's study examined the relationship between voice change and hormonal development particularly associated with pubertal maturation based on a comprehensive range of investigations, including stroboscopy /EGG, hormonal analyses and biometric measures (1997). Analyses of vocal function were obtained from phonetography, (*"a method used for registration of the total frequency range and the total dynamic range of the voice. The result is shown in a graph called a phonetogram, a voice area, or better a voice range profile ... The fundamental frequencies of several arbitrarily chosen tones are shown along the horizontal axis, and the corresponding sound level pressures are shown along the vertical axis."*(1997)). 48 boys and 47 girls between the ages of 8years and 19years, all musically gifted, participated in the study. Three boys participated in a longitudinal study involving phonetograms and hormone analyses bi-monthly for one year.

Measures of Fo derived from reading were related to height; pubic hair stage; testis volume; total testosterone and serum hormone binding globulin and demonstrated that in boys in pubertal stage II – IV *"The drop in sex hormone binding globulin for testosterone predicts the fall in the mean fundamental frequency in a reading situation (when under 219Hz).*

Pedersen (1982) found that between the ages of 13years and 15years serum testosterone increased and the Fo values were still above 195Hz; compared to the highest Fo value of 148Hz from the age of 15years with an apparent relationship between increased serum testosterone and either a lower upper ceiling of the Fo range or register breaks. At age 17–18years the boys demonstrated an adult voice.

Pedersen (1997) suggests that *"The highest semitone is variable and depends on training more than biology."*

These studies focus specifically on the hormonal influence and lead to the conclusion that *"Fundamental frequency of more than 200.Hz and serum testosterone of more than 10nmol/l probably represent values for a boy in puberty."* (Pedersen et al. 1986).

No.of Subjects	19	15	14
Age Grouping in years	8.7 - 12.9	13 - 15.9	16 - 19.5
Fo in continuous speech (Hz)	273	184	125
Voice range in continuous speech (semitones)	3.7	4.8	5
Total tone range (semitones)	34.4	37.5	41.4
Lowest biological tone (Hz)	158	104	72
Middle biological tone (Hz)	435	321	254
Height (cms)	143	157.1	180.6

(From: Pedersen et al. (1986) Fundamental voice frequency measured by electroglottography during continuous speech. A new exact secondary sex characteristic in boys in puberty.)

Table 15. Fo measures for 13-15-year-old boys (Pedersen et al 1986)

	Boy 1		Boy II		Boy III	
	Singer	Puberty	Singer	Puberty	Singer	Puberty
No. of measurements	5	1	1	5	3	3
Age. Years/months	14yr 1m - 14yr 9m	14yr 11m	14yr 2m	14yr 4m - 15yr	13yr 7m - 13yr 11m	14yr 1m - 14yr 6m
Lowest semitone (Hz)	147	131	98	87.3	116	65.5
Highest semitone (Hz)	1320	1320	1320	1320	1244	987
Tone range in semitones	38	40	45	47	41	43
Register shift (Hz)	524-587	330-392	330	330	349-392	262

(From: A longitudinal pilot study on phonetograms/voice profiles in pre-pubertal choir boys) (Pedersen et al 1993)

Table 16 Results of longitudinal comparison of 3 subjects age 13-15years (Pedersen et al 1993)

The relationship between the characteristics of the male voice change (speaking and singing) and biological changes at puberty has also been investigated by Harries et al (1997). None of the subjects (26 boys, age 13years and 14years at first recording) were choristers. Comprehensive assessments of maturation (standing height, weights, pubertal stage (Tanner classification), measurement of testis volume, salivary testosterone profile, ELG) were completed at three monthly intervals over a twelve month period (five assessments). Subjects underwent laryngoscopy and measures of voice Fo (mean and range speaking and singing) were obtained using ELG. The samples of speaking voice were derived from reading of two passages, the singing range was derived from an ascending and descending scale sung without using falsetto or vocal fry registers. The results were related to the Tanner and Cooksey classifications.

These researchers found an abrupt change in voice Fo in late puberty (between Tanner stages 3 and 4, (Tanner and Whitehouse 1976), but that *"measurable changes"* are occurring at an earlier stage and before voice 'breaking' is manifest.
This suggests that theoretically physical measures may provide evidence of change before it is auditorily discernible. A strength of this study is the frequency between assessments, however the age of the youngest subjects limits identification of changes related to the early stages of maturation. This studied supported the findings of Pedersen et al ((1986) of a relationship between testosterone levels and voice parameters.

7.7 Studies focused on singing

The adolescent singing voice has been extensively studied by Cooksey who devised voice classification guidelines as a reference for the stages of change of the singing voice of the male adolescent. Cooksey suggests that measures of aspects of singing provide information on the developing vocal mechanism and applied available data to formulate guidelines, (1977).

Five stages of development was identified from data on the *"total pitch range; tessitura (most 'comfortable' singing pitch range); voice quality (degree of constriction, breathiness and spectral configuration; register development; average fundamental frequency of speech samples"*, (register development and voice quality were not used for the voice classification).

Voice Classification		
Stage I	Midvoice I	early beginning of change
Stage II	Midvoice II	middle of change
Stage III	Midvoice IIA	climax of change
Stage IV	New Baritone	tapering period
Stage V	Developing or settling baritone	expansion and development period

Table 17 Cooksey voice classification

A subsequent study of vocal factors (tessitura, quality, register development); acoustic factors and physiological factors of 86 boys age 12-13years, (45 of this group did not have vocal training or experience) led to a revision of the 1977 guidelines. (1984). It is noted that in this study *"exceptional cases had to be taken into account."* and were inspected in relation to the variability of the high terminal pitches.

These researchers reported:-

- A difference pattern of change in the upper and lower limits of the singing range, with a gradual, inconsistent lowering of the top of the range compared to change in the lower limits in *"ever increasing intervals."*
- Instability in the upper range with increasing stability in the lower range.
- The stages of change are predictable.
- There is a reduction in range of about four semitones which is stable over the stages of voice change.

Voice quality and register were considered important with the finding of increased breathiness and constriction of the intrinsic muscles during phonation of the lower Fos, although it is not specified whether this is consistent both throughout a task and for all materials.

The physiological data (*"sitting and standing height, weight, chest size, waist size, total body fat, percentage of body fat, phonation time and vital capacity"*) was reported to be consistent with reported data, although the maximum phonation time was closer to adult levels than to the norms for adolescents.

The classification guidelines were applied in a subsequent study to assess the singing range and speaking Fo of 15 boys voices considered representative of *"prototypical pitch* *patterns".* Frequency references were presented by piano and pitch pipe for readings and vocalisations. The results were consistent with the voice classification guidelines except in respect of the speaking Fo from midvoice I with the pitch intervals above the lowest terminal pitch (singing) becoming wider. The researchers question whether this reflects more rapid growth patterns; it is not clear what this may be attributed to

White (2000) investigated formant characteristics and voice source features to obtain a fuller description of child voice. Forty four children (18 boys and 26 girls, age about 11years) with a *"relatively high level of singing experience"* were selected on the basis that children of this age *"are unlikely to be affected by factors relating to voice which are associated with the onset of puberty.";* however Pedersen et al (1982) suggest the features of premutational voice of *"a certain loss of voice power, and more frequent cases of indisposition of voice"* (Weiss 1950) may start at the age of 10 years.

The children in White's study undertook a range of tasks (a pre-learned song sung and repetition of syllable [pa:] both at three levels of loudness, (soft, mid, loud), and four vowels sung and spoken.
Systems of analysis used were:- Singing - Long-term average spectrum (LTAS); repeat syllables - inverse filtering of flow waveform; vowels – spectrogram analysis.

The results demonstrated that the spectral characteristics and the glottal waveform are influenced by loudness.
White raises important considerations :-

- Subglottal pressure differences should be controlled for voice source measurements of children.
- The formant frequency differences for sex and voice type found may result from a longer vocal tract in the boys compared to the girls, and the articulation of the vowels.
- Whether the results of this study are applicable to children with either more, or less training than this group of subjects.

Barlow and Howard (2002) studied the voices of 127 children, (singers and non-singers) using ELG to identify the vocal fold closed quotient.[2] The age range of the subject group is given as the youngest *"at least 8 years old, and the oldest not more than 18."*
The data derived from subjects aged 12 years and under is analysed as a single group on the basis that *"the laryngeal dimensions will vary by only a small amount for this age group."*, so there is no information provided regarding the distribution of ages and this is further confused by the tables for the 13 -18-year-old subjects which gives the mean ages as 13.6–16 years (females singers age 13-18); 14–16 years (female non-singers aged 13-18), and 13.6–15.8, (male subjects 13+).
Subjects read a ninety second section of 'The Story of Arthur the Rat', less than the recommended sample length (discussed in Chapter VIII), and sang a two octave scale, at *"as regular a volume as possible."* The researchers report that the reading sample was used to identify the mean speaking pitch.

From analysis of the pattern of the slope of the QxFx plots related to age, amount of singing training and gender, the researchers detected a strong correlation in the female subjects between the pattern of the Qx plot and the mean length of training. The correlation was not so evident in the younger group of male subjects, and in the older male subjects the indications are that different patterns reflect the effect of age.

From these findings Barlow and Howard concluded that *"voice source production of children changes in a predictable and measurable pattern with increased vocal training for prepubescent male and female children and also for adolescent females"*; although the results are derived from the singing sample only. No terms of reference are given to support a further statement that *"There was no indication in the study that the subjects who trained their voices professionally from an early age had suffered as a result."* (e.g.measures of vocal fold vibration temporal irregularity, or psychometric assessment).

The findings reported in 2002 were supported in further analysis of the data in *"discrete third octave bands."* again, to explore the effect of training, (2005).

[2] The closed quotient refers to the duration of vocal fold contact as a percentage of the entire vibratory cycle. This is presented in speech studio analysis as CQx – the percentage irregularity of the closed quotient. The QxFx provides representation of the %Qx value on the 'y'axis, against the Fx (Hz) on the 'x'axis. (Speech Studio analysis is discussed in Chapter VI)

Third Octave Bands (Boundaries in Hz)						
	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6
Female/unchanged male	196.0 - 247.0	247.1 - 311.0	311.1 - 392.0	392.1 - 494.0	494.1 - 622.0	622.1 - 784.0
Changed male voice	98.0 - 124.0	124.1 - 156.0	154.1 - 196.0	196.0 - 247.0	247.1 - 311.0	311.1 - 392.0

Table 18 Fo values for female and unchanged male voice compared to changed male voice (Barlow and Howard 2002)

Male subjects were put into groups according to the mean spoken Fo; (1) subjects with a mean spoken Fo of 220Hz and above, and (2) with a mean spoken Fo lower than 160Hz., (based on the Cooksey index of 'unchanged' and 'new, or settling baritone').
Grouping of the female subjects was based on the work of Pedersen; (1) Mean spoken Fo of 249Hz and above (unchanged); (2) Mean spoken Fo of 235Hz and below (changed)

Barlow and Howard report significantly similar mean CQx values for trained and untrained female singers in pitch bands in the lower octave; although higher CQx values in the upper three bands identified in untrained singers were statistically insignificant, this finding was reported as suggesting *"that there is an effect on vocal production of training female unchanged voices."*. Changed female trained and untrained voices were found to be similar and the researchers suggest that the effects of training are concealed by the effect of voice change.
The results for the males demonstrated higher mean CQx values in untrained pre-pubertal voices in bands 2 – 5 than those found in trained voices, but lower mean CQx values in band 6; although Barlow and Howard also report that *"untrained unchanged male singers exhibit decreasing mean CQ against increased pitch bands."* Unchanged trained singers demonstrated similar behaviours to those of the female unchanged trained singers, whereas the mean CQx values found in changed trained singers decreased with the higher pitch bands.
These researchers present various theories to account for the differing features:-

- the lower CQx values found in female untrained changed voices may be related to a reduced vocal fold contact area as a consequence of the growth of the larynx, particularly in relation to the widening of the angle of the thyroid cartilage.
- the untrained unchanged male singers may use a single register (chest) with the low mean CQx in the upper bands resulting from increasing breathiness in the higher pitches in contrast to the trained unchanged male singers who were found to have a higher mean CQx in the high band.

The results led the researchers to conclude *this study has demonstrated that singing training has a measurable effect upon the voice source."*

Whilst this would be expected, their argument appears inconsistent: it is suggested that the rise in CQx values in the highest pitch band found in females may be caused by forcing the voice, that it may be an artefact of singing, or it may be related to electrode displacement as the larynx rises on the higher pitches, whereas the higher mean CQx found in trained, changed male singers is interpreted as indicative of increase vocal efficiency as a result of training.

The results were derived from singing scales, and do not necessarily apply to other singing activities.

Williams et al (2005) reported the initial findings of a longitudinal study of choristers to investigate vocal behaviours using ELG. The subjects are recorded at six-monthly intervals and complete a range of tasks; counting from 20 – 1 at normal, loud very loud and quiet volumes, reading 58 words of The Story of Arthur the Rat and singing (sustained pitch varying the loudness, pitch glides, a two-octave scale and twenty-three words of a hymn sung over 34 notes). These assessments are supported by information obtained from questionnaires relating to past and current health, personality type and vocal progress, a self-rating of *"singing ability and that of other choristers."*, and a perceptual evaluation. Based on the results to date these researchers report the finding of levels of vocal fatigue above those found in the *"'normal' non-professional singing boy"* and lower levels of severe dysphonia .

Fuchs et al (2006) have undertaken a study to determine whether the beginning of mutational voice change can be identified from acoustic analyses. 21 choristers from a professional choir underwent a range of assessments, at three month intervals over a three year period. These researchers report that changes identified from analyses of a range of acoustic features are evident seven and five months before mutation onset and that vocal function is restricted six months before mutation onset.

These studies all generate information that is important to the knowledge base of this subject. A review of the literature exemplifies the comment by Pedersen, *"To some extent the different approaches to the phenomenon* (i.e. Fo) *depend on the researchers' background"* and brings to the fore the need for collaboration between researchers from different backgrounds to obtain comprehensive data and a real understanding of the many and complex factors.

7.8 Studies reporting on measures of Fo percentage irregularity

Little data is available on the quantification of irregularity.

Boltezar et al (1997) concluded that instability, specifically of pitch is the main characteristic of adolescent voice.

Bowen (1997) undertook a cross-sectional study using ELG on the effects of ageing on the human voice based on three age groups, (under 11 years; 35 –55 years and over 70years), and reported a mean percentage irregularity of 6.36 for the 6 male children, and a mean percentage irregularity value of 4.51 for the 6 female children, (average age of all children 9.2years).

In the absence of other data for children reference is made to work with adults.

Carlson (1995) suggests that normal voice demonstrates between 5% and 10% irregularity; this is qualified by reference to a vast range of from 4-6% to as high as 60% demonstrated by speakers regarded as 'normal'. Carlson reported mean irregularity for 'normal' speakers (the genders of the subjects is not specified) reading of 13.9% and speech of 18.4%.

Ptok et al.(2006) investigated the relationship between subjective evaluation of roughness and measurement of vocal fold cycle irregularity and reported a significant correlation.

Abberton (2002) comments on the variation in the occurrence of irregularity (perceptually identified as creaky voice) between genders and language which has not been studied to provide data on normative values, but refers to values in excess of 40% in dysphonic speakers compared to less than 10% in many normal speakers.

7.9 Summary

- Recognition of the need for more information on this subject precedes the recent interest, with early researchers raising questions which remain unanswered.
- The diversity of methodologies, including materials used, limits cross-referencing and comparison of studies and data.
- Information obtained for the paediatric population supports the view that children are not adults on a small scale, and that there is a need for specific data on children at different ages.
- Studies of children are complicated by their levels of co-operation, difficulty obtaining measures (ie because of their smaller physique), ethical considerations and subject recruitment.
- Individual and group variability undermine the relevance of group data and emphasises the need to relate individual results to group data and to monitor change in individuals.

- The diversity of backgrounds and research interests of investigators is evident from the studies referred to; these factors determine the focus and therefore the findings of the study. This is a weakness of all the studies referred to which do not adequately reflect the real complexity of this subject, and highlights the need for the integrated multi-disciplinary approach which is established in some clinical fields (eg. Neuro-rehabilitation).
- With the exception of the study by Weinberg and Zlatin (1970) the studies referred to all relate to 'normal' children.
- None involved any assessment of verbal skills or educational levels. yet most include a reading task in the protocol. The Sorenson study included a screening to exclude language / articulation problems.
- The study by Bowen (1997) is alone in providing information on the ethnicity of the subjects, (although other researchers refer to the geographical area from which subjects were recruited). In a multi-cultural society it is useful to identify how representative a subject group is of a particular population.
- Screening for hearing was included by Weinberg and Zlatin (1970) and Sorenson (1989) only.
- Few studies specified that the subjects had undergone an ENT examination.
- Little reference is made to respiratory function.

CHAPTER VIII METHODOLOGY

8 The Present Study

This study explores differences in aspects of vocal function in boy choristers in relation to vocal tasks, and over time. It is descriptive rather than rigorously experimental but uses physical quantitative methods for analysing the subjects' voices, with appropriate statistical treatment of parameters studied. The relatively small number of subjects precludes complex statistical treatments, (such as multidimensional scaling). Group and individual data are presented.

The study was set up in the context of the modus operandi and the requirements of the institution involved. (Appendix 2)

8.1 Objectives of the Study

The primary objective of this study was to collect data on this subject group. From a clinical perspective information on the condition and mobility of the vocal folds, (ENT examination/indirect laryngoscopy), auditory acuity (audiometric testing), and lung function tests(spirometry), were considered fundamental. An ENT examination is the minimum investigation required in a study of vocal function, and in studies of childrens' voice it should be supported by audiometric testing.

Underpinning the boys' ability to sing is the influence of maturation on the voice, therefore longitudinal biometric data was obtained to provide comparison between the physiological changes and the Fo and other analyses derived from three recordings made at approximately one year intervals.

Measurements derived from different tasks were intended to provide information on the influence of task on aspects of vocal function.

8.1.1 The Research questions

- What are the quantifiable characteristics of changes in fundamental frequency (mean, range and vocal fold vibrational irregularity) within the age ranges of 8–13 years in male adolescent choristers?

- Are these changes exclusively governed by physiological change or is there evidence of the influence of voice training?

- Are changes in vocal fold vibrational characteristics related to any of the measurements of age, weight and height?

- Can voice change associated with maturation be predicted from quantifiable measures?

8.1.2 The Research Protocol

The study design was based on a previous study of normal adult voice undertaken by this researcher in collaboration with a researcher from the Department of Phonetics and Linguistics at University College London.

The requirements in order to obtain ethical approval are rigorous, especially when the subjects are normal children attending voluntarily. The study was designed and undertaken by this researcher and supported by the ENT Consultant for submission to the ethics committee (District Research Ethics Committee, St.Bartholomew's Hospital, London).(Appendix 3)

8.1.3 The Subjects

The school headmaster approved the study and informed the parents. Although the headmaster stands in loco parentis, parental consent was obtained (Appendix 3).

All subjects were choristers at the cathedral choir school and met the criteria specified in the research protocol. The total number was 40, aged from 8.01years to 13.42 years (Mean age at first year of the investigation: 10.41yrs.) Subjects' ages and age interval between recordings are presented in Appendix 4.

Arrangements for attendance were made by the school matron; this resulted in some variation in the interval between the sessions; however, the sessions were arranged at the same time of day throughout the investigation although anecdotal reports by singers of time-of-day effects were not demonstrated in a study of adult females by van Mersbergen et al (1999). The eldest boys were assessed only once as they were in their final year at the school and it was not possible to follow them up. The remaining boys were assessed once a year over 3 years. The boys attended in pairs, usually from the same class; this was again determined by the practicalities for both the Cathedral and the hospital, but it was also intended to ensure no child felt isolated or intimidated as might have occurred if they attended alone.

There were no specifications in terms of activities or eating and drinking prior to the investigations except that voice recordings were not made within two hours of a performance or choir practice.

The boys came from different geographical and social backgrounds, but predominately from the South East of England; (one subject was of Afro-Caribbean origin, one originated from Australia). All spoke English as their first language.

The procedure and purpose of the investigations were explained to each boy on arrival and it was emphasised that they did not have to participate and could decline to undergo any of the investigations. All were happy to participate.

Because of the complexity of co-ordinating the five hospital departments involved in the study, as well as the arrangements with the choir school, the conditions under which the investigations were completed could not meet strict laboratory conditions.

8.2 The Questionnaire

A questionnaire used with the adult normal subjects was modified slightly to obtain information about health and habits that may be pertinent to voice care and use. (Appendix 5). No medical information was provided by the school for any subject.

The responses were reviewed before the voice recording session and any particular points followed up if necessary. The questionnaire was only presented when the subjects attended for the first time but their responses were reviewed with them on subsequent visits and revised where necessary.

CATEGORIES OF QUESTIONS

1) Health. (These questions focused on the upper airway, and features relating to temporomandibular jaw tension, (TMJ)).
2) Dietary Factors
3) Environmental factors relevant to laryngeal health
4) Music training, (including singing)

8.2.1 Rationale for Questions

8.2.1.1 HEALTH

The rationale for these questions was the relationship between respiration and phonation as discussed in chapter III.

TMJ tension is typically the domain of the dentist/orthodontist, with no published evidence of any relationship between TMJ tension and vocal function. The significance of movements and positioning of the articulators in singing as well as speaking is well-recognised and forms a central part of professional training; the significance of the posture of the jaw at rest appears to attract little research interest, although the degree of habitual tension will inevitably influence how it reacts in use.

Lindblom et al (1971) investigated the effect of movements of the lips, tongue, jaw and larynx on formant frequencies using model simulations to demonstrate that jaw movement, when other variables are constant, influences F1.

Lindestad et al (2004) reported on a study of laryngeal adduction asymmetry and concluded that this feature is *"probably of little importance for voice function."*, although questioning whether the subjects were compensating for the asymmetry, or whether the voice would have been even better if the structure and function were symmetrical.

Based on this researcher's clinical observations that patients presenting with voice problems (including choristers) frequently demonstrate TMJ tension, and as a breath holding behaviour is associated with jaw clenching the subjects were asked:-

(i) Do you ever clench your jaw?

(ii) Do you ever grind your teeth?

(iii) Are your side teeth touching when your mouth is closed?

8.2.1.2 DIETARY FACTORS

Hydration in relation to vocal function has been discussed with reference to previous studies, (Chapter IV).

White wine, spicy food and dairy products are all considered to possibly affect the vocal fold tissue, McCurtain (1989). More recently attention has been given to the relationship between voice problems (hoarseness) and gastroesophageal reflux. Gumpert et al (1998). reported a finding that gastroesophageal reflux and chronic laryngitis and hoarseness in children are directly related.

The subjects in this study were asked:-

What do you like to eat?

What kinds of food do you usually eat?

What do you like to drink?

What do you usually drink each day, (type and quantity)?

Because the subjects were boarders at the school their diet was fairly balanced and consistent.

8.2.1.3 QUESTIONS ABOUT ENVIRONMENTAL FACTORS

These questions focused on factors which have been found to be aggravants. Dust and dryness have been found to be aggravants in the working environment of teachers, (Viljanen, (1989) cited by Vilkman (1998)). Richter et al (1996. 2000) found that performers are not only affected by the hot, dry environment in an unhumidified theatre, but may also experience endogenous drying caused by an adrenal reaction stimulated by performance stress.

8.2.1.4 QUESTIONS ABOUT MUSIC TRAINING AND SINGING

All the subjects play at least one instrument. Gossett (1989) points out that voice teachers are inclined to oppose concurrent study of voice and a wind instrument, whereas musical instrument teachers support it and cites the conclusions of Henry Charles (1946); *"We are faced, then, with these significant facts: (1) the lower jaw may be changed from its natural position into an unnatural one, making its relaxation difficult in singing, (2) the lips are compressed to varying degrees with a tenseness which may tend to make the vocal tone metallic, (3) the stiffness in the placement of the tongue may be carried over into vocal study causing a disagreeable obstruction in passage of the tone. The numerous and diverse breathing methods practised by vocalists are paralleled by similar disagreements among instrumentalists. Thus, it is not difficult to recognize at least one reason for a vocal instructor's condemnation of instrumental breathing methods.* Gossett advocated concurrent study of oboe and singing.

There are few studies of the relationship between voice and playing a wind instrument, with most studies focusing on laryngeal behaviours in relation to respiratory function; (Gossett (2002), Bouhuys (1964) cited by Gossett (1989), King (1988 and 1989), Swoboda (1991, cited by Weikert et al (1999).

Weikert et al, (1999) studied the behaviours of the larynx and hypopharynx in two male saxophone players, both also amateur choir singers (baritone) with particular reference to the breathing techniques for playing a wind instrument and singing and found:-

- The larynx is kept in a low position while blowing to play the saxophone, described as *"equivalent to that in singing."*.
- The vocal folds adducted at the onset of tone and were predominately in the intermediate position.
- The epiglottis remained in an upright position.
- There was a slight inward and forward tilt of the apex and corniculate process of the arytenoid cartilages at the onset of tone.
- There was no evidence (on stroboscopy) of vocal fold vibration, amplitude changes or mucosal wave.
- Slight supraglottic adduction and some constriction occurred and was most notable during sustained swells and forte tones.

Weikert et al. suggested that *"The slightly constrictive function of the larynx in wind playing as described above is visible as an intermediate lateral contraction of the false vocal folds and as supraglottic adduction by way of a tensing of the larynx."* These researchers suggest that from a singer's perspective this laryngeal configuration correlates with that found in muscle tension dysphonia. Crucially they suggest that the pressure breathing for playing the wind instrument *"can lead to laryngeal signs of pressure breathing with laryngeal strain. Perhaps this limits the laryngeal motility which needs to be comparatively greater for singing than for playing the wind instrument."*

The behaviours required for playing wind instruments identified as potentially problematic to singing relate to supra/subglottal air pressure; jaw tension resulting from the embouchure requirements; lip tension and reduced tongue flexibility.

Twenty-one of the subjects in this study played a wind instrument, none played more than one wind instrument. (Appendix 5).

The last section of the questionnaire was related to singing. Of the twenty boys who said they found singing, or some aspects of singing, hard, ten identified the top, or high notes as being difficult.
Because of the constraint on questions which could be asked no information was obtained on any emotional/psychological factors.

8.3 The Investigations

All subjects underwent a range of investigations:-

- ENT examination (indirect laryngoscopy, and measurement of the vertical dimension of the larynx).
- Biometric measures
- Lung Function Testing
- Audiometric Testing
- Voice Recording

8.3.1 ENT examination

The condition and vibratory characteristics of the vocal folds underpin voice production and the associated vocal quality; therefore it is imperative that any study of voice includes an appraisal of the vocal apparatus to exclude any obvious structural or functional problem. This applies equally when the subjects are 'normal', (i.e. when they do not present with any known dysfunction or vocal difficulty), as when they present with a recognised problem. There is no known published data to show whether transient vocal abuse in childhood affects the vocal fold tissue in the long term.

8.3.2 INDIRECT LARYNGOSCOPY (IDL)

This term refers to the procedure of examining the larynx with the patient/subjects' active co-operation, (in contrast to direct examination by microlaryngoscopy under anaesthetic). This examination can be undertaken using a mirror, or nasendoscopy; increasingly this complemented by stroboscopy, (using a flexible nasendoscope, or a rigid oral 'rod') to provide an enhanced image.

8.3.2.1 MIRROR EXAMINATION

The patient/subject is seated facing the examining doctor and is asked to protrude their tongue, which is then gently held with a gauze while the mirror (which has been slightly warmed), is inserted to the back of the mouth and the oropharynx by pushing the uvula gently up and back. If a person finds it difficult to tolerate this procedure a topical anaesthetic is used to reduce sensitivity. The reflected image allows examination of "the base of the tongue, the anterior surface of the epiglottis, the valleculae, the pharyngeal walls, the pyriform sinuses, the posterior border of the epiglottis, the aryepiglottic folds, and the mucosa of the posterior commissure." (Aronson 1990).

The disadvantage for the patients/subjects is that it can be uncomfortable and it limits the ability to phonate because the tongue is constrained.

8.3.2.2 NASENDOSCOPY

This involves using a fiberoptic laryngoscope (a flexible fiberoptic bundle with the light source and magnification integral in the tip of the scope used with constant or stroboscopic light), which is passed through the nasal cavity into the oropharynx, to enable visualisation of the larynx. Insertion of the nasendoscope can be uncomfortable and a topical anaesthetic may be used to desensitise the nostril and the oropharynx.

8.3.2.3 STROBOSCOPY

The use of stroboscopy was first recorded in 1878 (Bless et al. 1987). Bless et al suggest that its application was not promoted because technical developments were slow, and because clinicians did not understand the importance of the vibratory characteristics of the vocal folds. The stroboscopic flashes may be synchronized with the frequency of the vocal fold vibration giving the visual illusion that the vocal folds are static. If the emission of the stroboscopic light is not synchronised the light impulses coincide with a different phase of the vibratory cycle creating the impression of successive cycles in slow motion, enabling the clinicians to examine the condition, configuration, movement, vibratory characteristics, including the mucosal wave, and timing of the opening and closure phases of the vibratory cycle. This information is important to the differential diagnosis and management of pathologic conditions, (Prytz (1987)).

Several considerations determined the type of examination used for this study.

1 The subjects were all 'normal' with no suspicion of any laryngeal abnormality.

2 The subjects were all children who, although they were exposed to challenging experiences as choristers, could nonetheless, find the clinic environment intimidating. Any procedure, therefore, had to be non-invasive and as discrete, and non-threatening as possible.

3 No dedicated time was allocated for any of the procedures which were undertaken during the routine clinic sessions, necessitating an economy of time.

Taking account of these factors the choice of procedure was mirror examination, with the use of nasendoscopy if it was not possible to obtain an adequate view.

8.3.3 THE EXAMINATION PROCEDURE

The examination was undertaken by an ENT Consultant specialising in voice, and involved the following examinations:-

Nose - to assess the airway patency.

Ears - to view the eardrum (and identify the presence of wax) prior to hearing testing.
Oropharynx (including the tonsils) - to exclude evidence of any infection.
The larynx /vocal folds - to assess the condition and mobility of the vocal folds.
The vertical dimension of the larynx (from the lower border of the cricoid cartilage to the centre of the thyroid notch) was measured using a calliper. (Appendix 6).

8.3.3.1 RATIONALE FOR MEASURING THE VERTICAL DIMENSION OF THE LARYNX

Williams and Eccles(1990) reported their findings that there is a correlation between the external vertical dimension of the larynx and the length of the vocal fold, and, based on a study of 115 healthy volunteers, that this dimension is related to voice Fo. The researchers (Williams and Eccles.1990), concluded *"we are now able to predict with some degree of accuracy what an individual's natural fundamental frequency should be relative to the size of the larynx."*

This finding was not supported by Laukkanen et al (1999) who caution consideration of measurement accuracy in the interpretation of results because of the difficulty identifying the vertical laryngeal size (especially in females), and determining the centre of the thyroid notch. These researchers also comment on laryngeal asymmetry.

Measurement of the external laryngeal dimension was therefore included in the biometric measures taken to collect data on this feature. However, because of the significantly smaller dimensions of the child larynx it proved very difficult to take this measurement, (as found by Laukkanen et al), particularly with the smaller and younger children.

A summary of the results is presented in Appendix 7.

8.3.3.2 RATIONALE FOR ASSESSING PATENCY OF THE NASAL AIRWAY

Barelli (1994)considers the importance of the nose to health, and specifically to respiratory health to be underestimated. The resistance to the air stream from nose breathing is approximately 50% greater than from mouth breathing, achieving 10-20% more uptake of oxygen; (breathing for speech is oral to allow quick inspiration).

8.3.4 Findings of the ENT examinations

The findings of the ENT examinations were documented on a record form (Appendix 3(i)). The following were noted:-

Ears Retracted right membrane; Middle ear effusion (left) – (1 subject).
Fluid (right ear) - (1 subject)

Nose 23 subjects reported a blocked nose, catarrh or sinus problems that troubled them; 11 of this group could not comfortably nose breathe.

12 subjects reported being aware of getting a blocked nose; 8 of this group were not troubled by it.

5 subjects reported that they did not have any nasal problems.

Vocal Folds

The view of the vocal folds was restricted because of the shape of the epiglottis (3 subjects).

Enlarged tonsils (3 subjects)

Poor vocal fold apposition (2 subjects)

Tiny vocal fold nodules (2 subjects)

Posterior gap (2 subjects)

Pink vocal folds (6 subjects)

Mucous on vocal folds (1 subject)

One subject required a topical anaesthesia.[3] The results of studies of the effect of topical anaesthesia on voice Fo (adult subjects) differ. Sorensen and Horii (1980) demonstrated significant differences in Fo perturbation, but urged caution in the interpretation of the findings because *"As with any anesthetization studies, the issue of the extent of the sensory deprivation and possible contamination of the efferent system could not be delineated precisely"* Furthermore in the Sorensen and Horii study the anaesthetic was *"dripped on the vocal folds"* during phonation. In the present study the spray was applied intra-orally only; however the voice recording was delayed by one hour to ensure that any effect from this had worn off.

Any findings pertinent to the boys' health, or relevant to their singing activities were reported to the School doctor, and the choirmaster, and recommendations were made for follow-up as appropriate. Only one subject had presented with any symptoms that may be associated with vocal function (ie a cold; this subject was not excluded as there were no symptoms evident in relation to vocal function and no vocal difficulties reported).

The finding of some feature relating to laryngeal health in 15.3% of the subjects demonstrates that an ENT examination is essential.

[3] Xylocaine Spray, (Lignocaine base 10mg). Administered in metered dose via a spray nozzle. It is used to provide surface topical anaesthesia for the introduction of instruments including into the respiratory tract. It is effective within 1-5 minutes of administration and remains effective for 10–15 minutes. When used in the oropharynx it may interfere with swallowing and increase the risk of aspiration. Biting trauma can result from numbness of the tongue or buccal mucosa. It is advised that eating and chewing gum are avoided for at least one hour after use. Symptoms of hoarseness and voice loss are only associated with application to the laryngeal mucosa before endotracheal intubation.

8.4 Biometric Measures

This study sought to relate vocal function (mean Fo) to maturation, an indicator to this process being growth. It was therefore relevant to obtain basic pertinent measures. Ethical constraints precluded x-ray procedures (to identify skeletal development), physiological assessments such as those undertaken by Pedersen et al, or visual inspection to identify penis, testes and pubic hair development.

Tanner et al (1966) introduced longitudinal-type standards for use in following the growth pattern of individuals for clinical purposes, or for routine monitoring of healthy children. (These differed from the growth standards derived from cross-sectional survey data which are used for comparison of population groups.)

The measures presented here are based on United Kingdom cross-sectional reference data (Child Growth Foundation 1996/1; the format was updated in 2002).

Each subject was measured by a specialist paediatric nurse. (A sample of the record form is presented in Appendix 3(ii))

8.5 Lung Function Testing

The limitations on the scope of investigations as previously explained led to the choice of simple spirometry which provides an objective measure of lung function in quiet breathing as the preferred measure.

Measures were derived from standard lung function testing equipment and the tests were conducted by lung function technicians.

Subjects were asked to breathe in through a mouth piece with nose clips, to their total lung capacity (TLC), and to then blow out as forcefully as possible down to their residual volume (RV) and to then breathe in again to their TLC. This was repeated three times, allowing an interval of quiet breathing between successive measurements.

The results provide information on (i) the forced vital capacity (FVC), (ii) the volume forcefully expired in one second (FEV_1) from which the ratio of FEV in respect of FVC can be derived and (iii) the peak expiratory flow rate (PEFR), (the highest flow realized during forced expiration from full inspiration. These measures provide a useful index of lung function; however, Hough (2001) points out that values are influence by posture and effort.

8.5.1 RATIONALE

A measure of respiratory function was included to verify that the subjects' respiratory function, as measured by spirometry, fell within normal limits. This was considered relevant because of the relationship between breathing and phonation as referred to in

Chapter III and therefore observation of breathing behaviours and measurement of respiratory capability is essential to voice evaluation, (Boone 2005).

Rosenthal et al (1993) undertook a study of 772 children (455 male; 317 female) to obtain more recent data than the previous standards for UK schoolchildren,(1979). These researchers particularly questioned whether predicted mean values change with increasing height. Unsatisfactory results were noted to occur in children of less than 125cms height, (three subjects in the present study were of less than 125cms height).

The results of that study demonstrated a linear relationship between increases in lung function measurements and height both before and after puberty, with a sudden increase observed during puberty. In a second study Rosenthal et al (1993) concluded that *"profound changes in pulmonary function"* in males associated with puberty are *"mostly related to thoracic size."*

Six subjects in the present study were on medication for asthma and one subject reported a 'wheezy' cough. The fact that all the spirometry results were within the normal range is consistent with the finding of Konig (1981) who reported that routine pulmonary function tests gave normal results in children with chronic cough without wheezing, who were subsequently diagnosed as asthmatic, and Fardy (2004) who reported that results of spirometry undertaken between episodes of asthma may be normal.

8.6 <u>Audiometric Testing</u>

8.6.1 <u>RATIONALE</u>

The relationship between auditory acuity and speech development, behaviour, and education is widely researched and the importance of early identification of hearing difficulties is well recognised, (Haggard and Hughes (1991)), with evidence of the effect on voice Fo.

- Elliott et al (1970) demonstrated the dependence of control of voice Fo on auditory feedback in an experiment in which subjects (adult) matched the voice Fo to an auditory target frequency under different conditions, including masking for both air and bone conduction.
- Sorensen (1989) stated that a diminution of auditory sensitivity by 25dB at 500, 1000 and 2000Hz in either ear is *"known to affect"* vocal Fo characteristics.

High frequency sensorineural hearing loss is more prevalent in older male children, (grades 9–12) Roeser and Northern (1981).Axelsson et al (1987) attributed a higher incidence of hearing loss in boys to the more aggressive and noisier leisure activities of boys and a genetic factor. A child with a high frequency hearing loss will hear the lower frequency speech sounds, but the higher frequency sounds (eg sibilants) will be distorted.

This section will not explore the physiology of hearing. However, brief reference is made to middle ear disorders, (serous otitis media), as the most common cause of childhood hearing difficulties, (Roeser and Northern 1981). Downs (1988), suggested that the prevalence of middle ear disease in children aged 0–6 years is 20–30%; Tos (1979) suggested that serous otitis media affects up to 90% of children at some point, (both researchers cited by Haggard and Hughes, 1991).

Whereas this condition may resolve spontaneously, long-term middle-ear disorders can adversely affect children's learning, and studies cited by McCormick (1994) indicate that linguistic and educational progress can be affected by a temporary fluctuating conductive hearing loss. *"The invisible nature of this disabling condition is such that it strikes at the heart of the communication system used by humans affecting not only receptive and expressive language facility but also possible social and emotional development."* (McCormick 1994)

Advances in audiology, including neonatal hearing screening, have significantly improved the early identification of hearing status, and rehabilitation for children with hearing disorders, (Parker 2002). Nonetheless, hearing status should not be assumed and it remains appropriate to include an assessment of hearing in any study of voice.
Critical features of hearing problems are that:-

(i) the problem may be fluctuating.
(ii) the severity can vary between profound and slight.
(iii) the loss may not be uniform across all frequencies.

Definitions of degrees of hearing loss based on pure tone audiometry are not standardised giving rise to some variation between clinics, Roeser et al (2000); however, a reference point is the classification system by Northern and Downs (1991).

Classification	Children	Adults
Within normal limits	0 - 15 dB	0 - 25dB
Slight	15 - 20dB	26 - 40dB
Mild	25 - 30dB	41 - 55dB
Moderate	30 - 50dB	56 - 70dB
Severe	50 - 70dB	71 - 90dB
Profound	70+ dB	91+ dB

Table 19 Classification of Hearing loss (in db) for children and adults. (Northern and Downs 1991)

8.6.2 Audiometric Testing

8.6.2.1 PURE TONE AUDIOMETRY

It was assumed, in the absence of any evidence to the contrary, that all the subjects participating in this study had normal hearing and that pure tone audiometry would provide the necessary information, although combined audiometric screening and tympanometric screening to identify both sensorineural hearing loss and middle ear disorders is widely used in screening programmes, (Roeser et al. 2000).

Pure tone audiometry identifies the threshold levels at which a range of frequencies, (pure tones), emitted through earphones, are perceived by the individual. This is recorded on an audiogram.

8.6.2.2. AUDIOMETRY PROCEDURE

Testing was undertaken by an audiologist, in a sound-proof booth to eliminate distraction from environmental noise.

Pure tone stimuli from 250Hz through to 8kHz were presented to the subject through TDH-39 headphones in gradually decreasing steps of 10dB. When the subject stopped responding, the intensity was increased in 5dB steps until the subject again responded. This procedure was repeated three times for each frequency to determine the thresholds, thus enabling the examiner to detect even slight losses.

The testing was repeated at yearly intervals over a three year period. The results for a few subjects who demonstrated some deviation from a normal response are shown in Appendix 8; all other subjects were found to have normal hearing. All results were reviewed by the ENT Consultant and if necessary reported to the School doctor.

8.7 Recording Procedure

Voice recordings were taken after the other procedures had been completed and after the subjects had a short break and drinks to maintain hydration.

8.7.1 Recording Environment

Deliyski et al (2005) state that *"Environmental noise represents a serious threat to acoustic voice analysis."*, and cite the recommendation of the National Center for Voice and Speech, USA, (1995) that recordings should be made in a sound-treated room with *"ambient noise less than 50dB"*. These researchers referred to a study of the effect of

the computer fan noise on voice analysis derived from computer systems which indicated that although jitter and shimmer measurements increased in relation to the increase in noise, the Fo was relatively unaffected, (Perry et al, 2000).
The results of a subsequent study by Deliyski et al (in press, cited by Deliyski et al, 2005) on the effect of noise on the *"accuracy, reliability, and validity of acoustic voice quality measurements"* led these researchers to conclude that when acoustic analysis is used as part of a clinical assessment of voice it is essential that the environmental noise is measured.
The voice recordings for this study were made in a sound-treated room; no measures of the environmental noise level were taken.

8.7.2 <u>Materials</u>

Zraick et al (2005) stated *"Currently, there are no internationally standardized methods for the instrumental and / or perceptual evaluation of voice."*
The choice of materials for this study intended to provide a comprehensive sample of voice use in different conditions. It took account of the abilities and tolerance of the subjects, including the time taken to complete the recordings.
The hymn chosen for the sample of singing was selected by the Choirmaster; the reasons being that all the choristers were familiar with it, that the frequency range was typical for the material used in the cathedral (12 S/T), and that it included a descant verse, (descant is the melodic line above and harmonizing with the basic hymn tune). Pitch glides and a two octave scale were used to compare vocal function for a range of tasks. The sustained vowels provided samples of relatively steady phonation in using a stable articulatory posture.

A reading passage was used to provide a consistent and replicable sample of connected speech. Initially two passages were used; *'The Story of Arthur the Rat'* (Abercrombie, 1967, after Henry Sweet, 1895[4]), and *The Rainbow Passsage* (1949). However 'The Rainbow Passage' was discarded when it became apparent that much of the vocabulary was too difficult for the younger subjects.

'The Story of Arthur the Rat' is widely used in clinical practice in the U.K. (Appendix 3(iii)). It combines narrative and direct speech and provides a sample which typically

[4] Henry Sweet (1845 – 1912). An authority on Anglo-Saxon and the history of the English Language, he was regarded as a founder of modern phonetics. In 1874 he wrote a 'History of English Sounds'.and was Reader in phonetics at Oxford University, (1901).

takes approximately two minutes to read, suitable for voice measurement, (Howard, 1998). Horii (1975, cited by Coleman and Markham (1991)) reported that analysis of one sentence of the 'Rainbow Passage' (Fairbanks 1949) to be adequate to estimate the Fo, of a paragraph within + / - 3.)Hz; Atkinson (1976) reported a finding from analysis of the voices of adult males speaking a simple sentence, that intraspeaker variability was comparable to interspeaker variability over a period of one year.

Abberton (2005) recommends about 1000 segments to provide a suitable sample (The Story of Arthur the Rat is 997 segments).Reporting on the complex nature of 'phonetic balancing' Abberton concluded that it is not necessary if the reading time of a passage is at least two minutes. The vocabulary used in 'The Story of Arthur the Rat' is appropriate for children and although some may consider the sad ending unsuitable, none of the subjects were at all perturbed by it. The disadvantages were (i) that the subjects wanted to use character voices, (Abberton, (2005) advises that direct speech should be avoided), and (ii) that those subjects who were recorded three times, were bored by it.

The final sample of connected speech elicited through conversation was intended to provide a sample of typical voice use, and, specifically, habitual pitch. Although any questions about family and personal matters were prohibited it was possible to ask questions about school activities, progress with music instruments and sporting events. Conversation was ongoing until a two minute sample of connected speech had been obtained.

Zraick et al (1999) investigated the influence of task on habitual pitch and reported that the nature of the speaking task may determine the habitual pitch and questioned whether the speaking Fo was affected by the duration of the speaking task. Subsequently these researchers investigated the effect of the duration of the speaking sample on habitual pitch and found significant differences between a 30-second speaking sample, and a 60-second speaking sample. As well as recommending that the duration of a sample of connected speech should be at least one minute, they suggest that a measure of habitual pitch could be derived from the average of a range of speaking tasks of various durations.

None of the materials were monitored for amplitude; however overloading was avoided.

8.7.3 Equipment

Data acquisition was made using a portable Laryngograph Microprocessor, (PCLX programme), and a Sony Digital Audio Tape-Corder TCD-D10).

The speech signal was recorded using a Sony Electret Condenser Microphone ECM-CR120 The recordings were analysed using the Laryngograph Speech Studio system.

8.8 Rationale for choice of perceptual evaluation scale

Webb et al (2004) studied the reliability of evaluation scales and found the ratings of the laryngeal parameters of the Voice Profile Analysis (VPA) more reliable than the supra-laryngeal parameters, but less accurate than ratings using the GRBAS concluding the scope of the VPA compromises the reliability which was found to be *"poor to moderate"*. The reliability of the overall voice rating using the BVP was found to be good, but reliability of the other, constituent, parameters ranged from poor to moderate; however, they concluded from a detailed reliability analysis that the GRBAS scale is a reliable and robust tool for clinical use. Dejonckere et al (1993) found it *"quite reliable and of clinical relevance for evaluating the severity of hoarseness."*, hence the choice of the GRBAS scale for this study, although the subjects' voices are all considered normal.

CHAPTER IX RESULTS AND DISCUSSION OF Fo DATA

9 *Fo data; average data for all age groups*

This study aims to reflect the dynamic processes of voice use and voice maturation by relating the voice measurements to different materials, and according to age. The average values for all the age groups are presented to introduce the results according to age group with reference to the parameters of mean Fo and Fo range.

The fact that the voice Fo lowers as boys mature is widely researched and indisputable. Figure 1 summarises the Fo values obtained as a function of age and shows the downward trend in mean Fo for reading, speech and vowels.

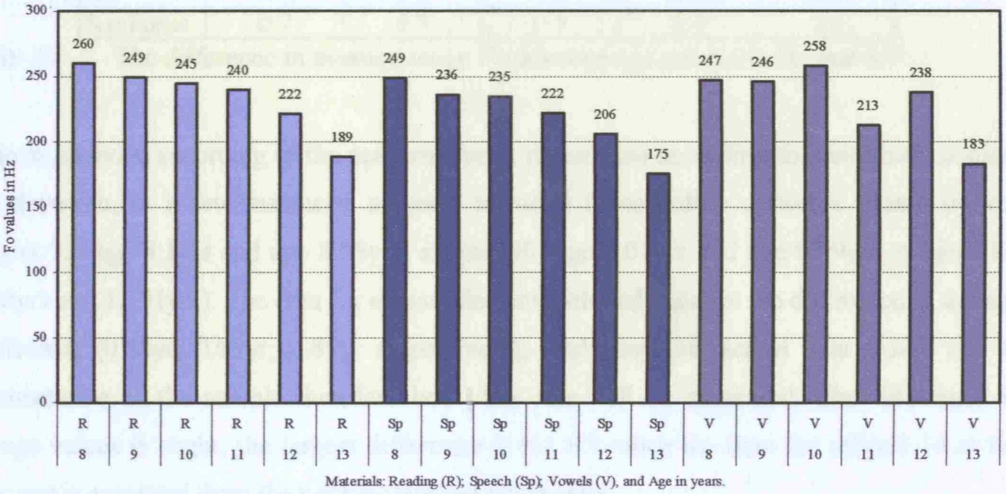


Fig. 1 The average of the mean Fo values derived from reading,(R), speech (Sp), and vowels (V), as a function of age (in years).

The results derived from sustained vowels differ slightly; however, there is a tendency for subjects when asked to sustain a vowel, to use a singing style, which may account for the less consistent downward trend.

9.1 *Reading*

The group average mean Fo (DFx2 values) derived from reading are presented by age at 12 month intervals and demonstrate the lowering of Fo from 260Hz to 189Hz between the ages of 8.01 years and 13.42 years ; a difference of 71Hz, (5.5 S/T).

This is not an even progression and is characterised by the greatest lowering in average mean Fo occurring between the ages of 12years and 13years. Table 20 shows the difference in Hz and S/T in the average mean Fo between age groups with a difference of 2.8 S/T between the 12-year-old and 13-year-old subjects, in contrast to a change of 0.7 S/T over the one year period between ages 8 years and 9 years.

	Age Groups (in years)				
	8 - 9	9 - 10	10 - 11	11 - 12	12 - 13
Hz	10.8	4.5	4.8	18.4	32.8
Semitones	0.7	0.3	0.3	1.4	2.8

Table 20 The difference in average mean Fo between age groups in Hz and S/T.

Subjects attended according to the academic year, rather than according to their chronological age, therefore, in a few instances, subjects attended twice within a twelve month period. (subject 35: age 8.1yrs and age 8.98yrs; subject 40: age 8.01yrs and age 8.99yrs; subject 12: 12.02yrs and 12.91yrs). The data for all samples are included because the difference in the age is relevant; (0.88yr; 0.98yr; 0.89yr respectively); excluding one set of data would not be representative of the sample therefore both data sets will be presented. The difference in average values is slight; the largest difference is 0.1 S/T when the data for subject 14 at the older age is extracted from the twelve-year-old group data.

9.2 *Speech*

The average mean Fo values derived from speech demonstrate the same trend as the reading samples with an overall lowering of Fo of 73Hz (6.0 S/T).

Comparison of change in the average mean Fo between consecutive age groups for reading and speech shows some variation; the lowering is more conspicuous between the ages of 12years and 13years in both reading and speech. (Table 21).

Age (in years)	8 - 9	9 - 10	10 - 11	11 - 12	12 - 13
Reading	0.7	0.3	0.3	1.4	2.8
Speech	0.9	0.1	1.0	1.3	2.8

Table 21 Summary of the difference in semitones in average mean Fo values derived from reading and speech between consecutive age groups.

The mean and mode Fo values for reading and speech are comparable, the only notable difference is that the average modal value for speech in the eight-year-old group is higher than the mean value, (mode 272: mean 249: difference 1.5 S/T).

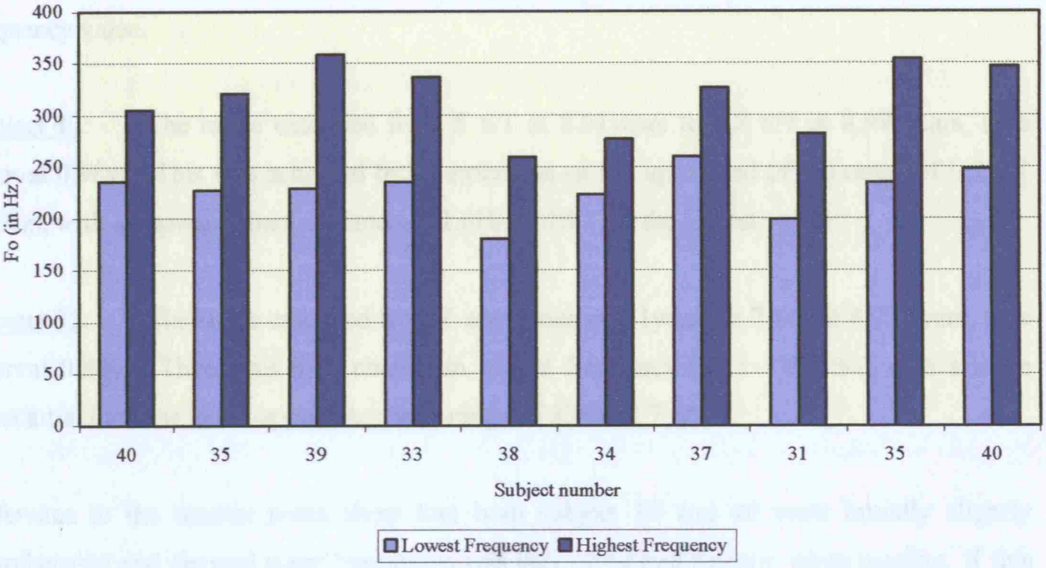
Group data is relevant when compared to existing data but must be reviewed in the context of the sample size. Review of the data for each subject within the group identifies some substantial variation which warrants inspection. Because the focus of this study is vocal function in relation to maturation the data is reviewed for each age group progressively to allow comparison over time, and between reading and speech materials.

9.3 *8 Year Age Group*

9.3.1 READING

The mean Fo values derived from reading for subjects at age 8 years show the extent of variation. The lowest value is 215Hz and the highest is 288Hz; a difference of 5.1 S/T. Although the difference between the mean Fo and the group average was notably lower for three subjects, (Subjects 31.34.38; S/T difference of 2.2, 1.4, and 3.3 respectively) this is considered in the context of the small sample and the individual frequency range.

9.3.1.1 Frequency range for each subject in the age group and discussion of selected individual data.



Subject:	40	35	39	33	38	34	37	31	35	40
Age (yrs):	8.01	8.1	8.24	8.32	8.47	8.65	8.75	8.88	8.98	8.99
S/T range:	4.4	5.99	7.76	6.18	6.3	3.7	3.9	5.99	7.1	5.8

Fig 2 The lowest and highest values of the Fo range derived from reading for subjects age 8 years is shown with the age in years and the total S/T range for each subject.

Inspection of the data for the subjects referred to above (subjects 31.34.38) shows that none of the upper values differ substantially from the average. The lowest value of the range for subject 38 (180Hz) is 48Hz, (4 S/T), lower than the average and is reflected in a wider range of 6.3 S/T, compared to the group average of 5.8 S/T.

The higher than group average mean value for subject 37 results from a higher value at the low frequency end of the range. The lowest and highest values of the range for these four subjects are compared to the group average:-

Fo (in Hz)	Average	Subj 31	Subj 34	Subj 37	Subj 38
Lowest	228	199	223	260	180
Highest	319	282	276	327	259
Semitones	5.8	6.0	3.7	3.9	6.3

Table 22 The lowest and highest value of the Fo range and the S/T range for four subjects discussed is compared to group average values for this age group, (8 years).

The subjects who were recorded twice whilst aged eight years, showed an increase in the overall frequency range resulting from a higher upper range, with little change in the lower frequency value.

Subject 40: The range extended from 5 S/T at 8.01years to 5.8 S/T at 8.99 years, (age interval 0.98yr). This was achieved by an extension of the upper end of the range of 0.9 S/T (18Hz), with an upward change of merely 1.0Hz (0.1S/T) in the lowest value.

Subject 35: The range extended from 6 semitones at 8.1years to 7 S/T at 8.98 years, (age interval 0.88yr). There was little change in lowest frequency (8Hz – 0.6 S/T, with a more substantial increase in the upper frequency range of 33Hz (1.7 S/T).

Reference to the session notes show that both subject 35 and 40 were initially slightly apprehensive and showed some hesitations and lack of overall fluency when reading. If this were the reason for a wider frequency range it would be expected that the probability of values would be weighted at the lower end of the range because of the vocal behaviours associated with interjections and prolongations.

Values derived from spontaneous speech for this age group presented and compared to those derived from reading.

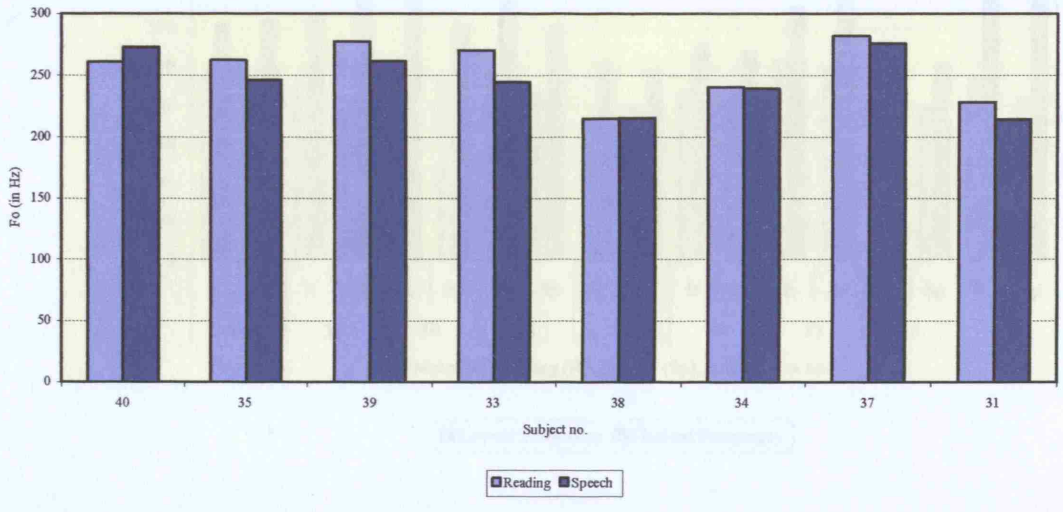


Fig 3 The mean Fos derived from reading and speech are compared for 8-year-old subjects.

Typically the mean Fo values for speech are slightly lower than those for reading, suggesting that the results are related to vocal behaviours associated with task.

9.3.2 *Spontaneous Speech Data*

The average mean Fo for speech is 249Hz; the group range is from 214.0Hz to 276Hz (4.4 S/T).

The highest mean Fo (subject 37. 276Hz) differed from the group average by 1.8S/T, and the lowest mean Fos (subject 31 – 214Hz and subject 38 215Hz) differed from the group average by 2.6S/T and 2.5S/T respectively.

The average range of samples of spontaneous speech is 5.9 S/T; however, this is distorted by the two exceptionally wide ranges used by subject 35 and if these samples are taken out the group average of 4.5 S/T is more usual. If the range at 8.1 years is excluded the average becomes 5.2 S/T, and if the range at 8.98 years is excluded it is 5.3 S/T. (This highlights the relevance of including both data sets for this subject without any clearly defined rationale to determine which might be excluded).

The frequency range used in spontaneous speech is compared to that used in reading.

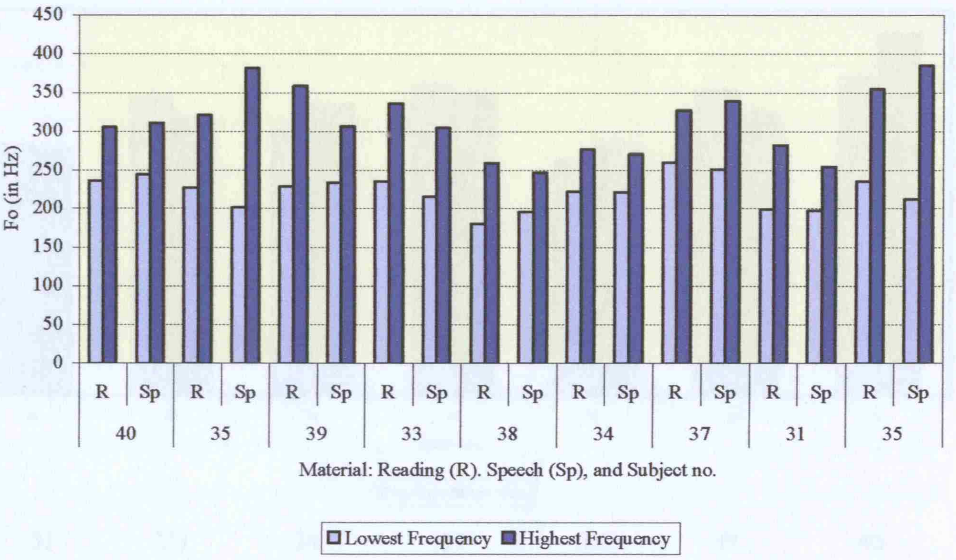


Fig 4 Comparison of Fo ranges derived from reading and speech for subjects age 8 years. (Age range 8.01 – 8.88years).

This comparison demonstrates that most of the subjects use a comparable or more restricted range in speaking than in reading, the exceptions being subjects 35 and 37.

9.3.3 *Mean Fo of sustained vowels*

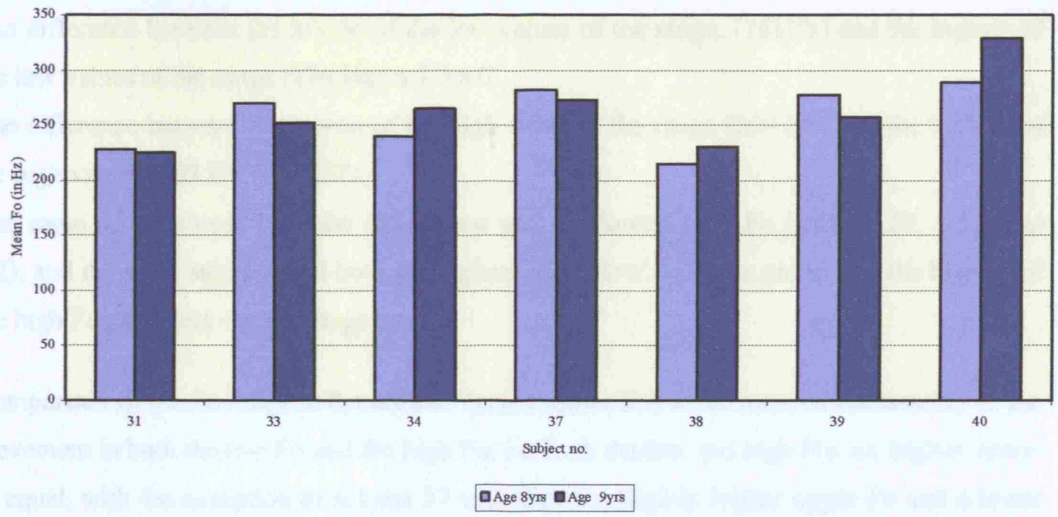
A sampling of the mean Fo derived from sustained vowels for shows variation in the relationship to the other tasks (Fig 1), but does not provide useful data, because of the different ways in which the subjects completed the task. (The value given for vowels represents the average derived from the vowels /a//u//i/ and /ɜ/, and does not reflect the intrinsic pitch of vowels).

9.4 *Data for subjects age 9 years*

Data derived from reading for subjects age 9 years compared with the results for the same subjects at age 8 years.

The lowest mean Fo derived from reading for the 9-year age group is 212Hz and the highest value is 328Hz. producing an average value of 249Hz. The value for subject 40 is exceptional (328Hz); if this sample is extracted the group average becomes 244Hz.

Comparison of the mean Fo for subjects recorded at ages 8 years and 9 years shows that of the seven subjects, three, (subjects 34, 38 and 40), used a mean Fo at 9 years that was higher than that used at 8 years; the remaining four showed a slight drop in mean Fo.



Subject:	31	33	34	37	38	39	40
Age Interval (in years)	1.09	0.98	1.08	1.05	1.01	1.04	1.0

Fig 5 The mean Fo derived from reading compared between subjects age 8yrs and 9 yrs.

9.4.1 *__Fo range – Reading__* (Subjects age 9 years)

The average values for this group are:- lowest Fo of the range: 218Hz ; highest Fo of the range: 310Hz. Range in S/T: 6

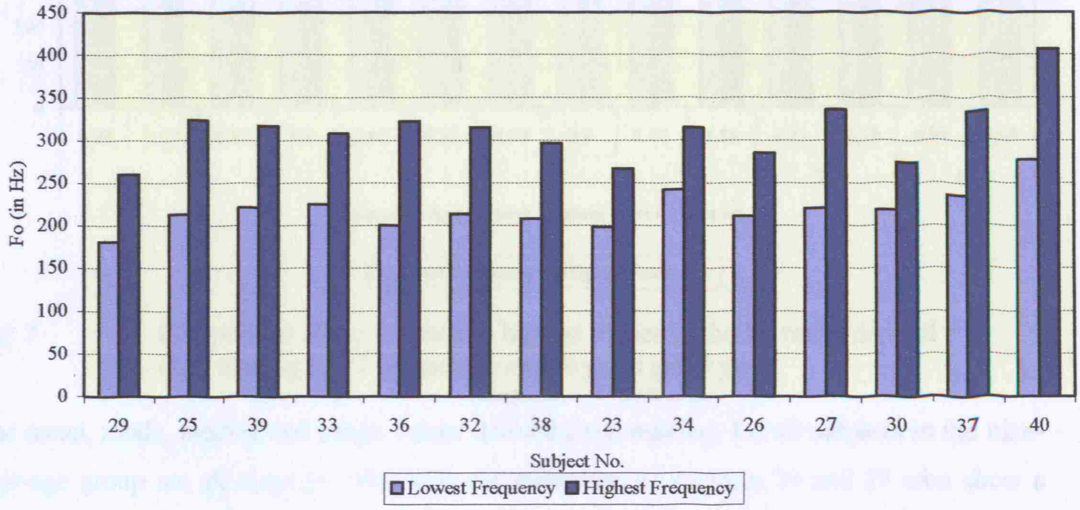


Fig 6 The Fo ranges for subjects age 9 years.

The difference between the lowest of the low values of the range, (181Hz) and the highest of the low values of the range (276 Hz) is 7.3 S/T.

The difference between the lowest of the high value of the range (260 Hz) and the highest of the high values (407 Hz) is 7.7 S/T.

The same subjects used both the lowest low and the lowest high Fo (subject 29, S/T range 6.2), and the same subject used both the highest of the low Fo in the group and the highest of the high Fos. (subject 40, S/T range 6.6).

Comparison of the Fo range at 8years and 9years shows that an element of consistency in the movement in both the low Fo and the high Fo; i.e. both the low and high Fos are higher, lower or equal, with the exception of subject 37 who shows a slightly higher upper Fo and a lower low Fo.

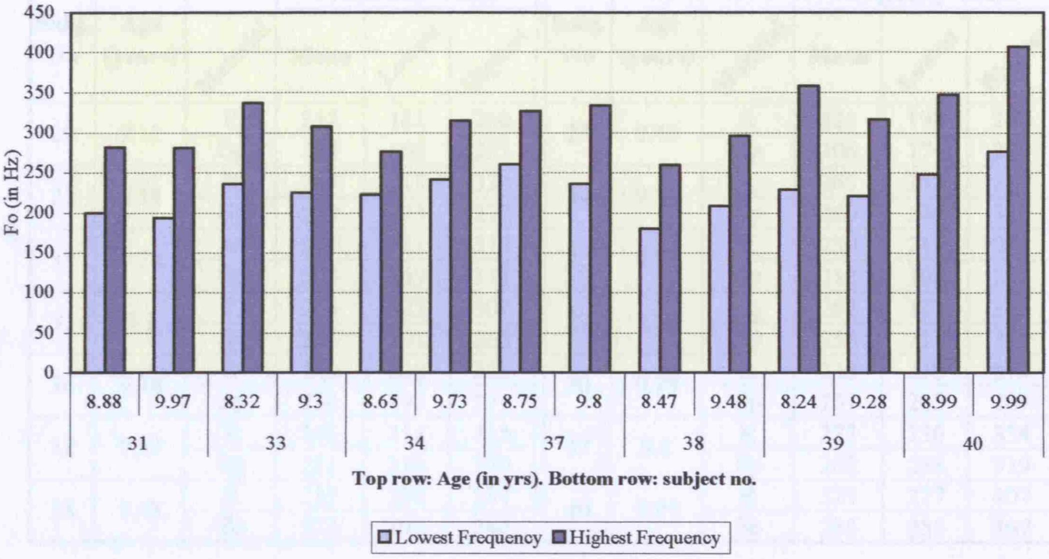


Fig. 7 Comparison of the lowest and highest values of the Fo range derived from reading for 7 subjects at ages 8 years and 9 years.

The mean, mode, median and range values derived from reading, for all subjects in the nine-year-age group are all close (< 7Hz) with the exception of subjects 29 and 27 who show a difference of 11Hz (mean 211Hz, mode 223Hz: 0.9 S/T) and 14Hz (mean 262Hz, mode 250Hz: 0.7 S/T) respectively between the mean and mode values.

Comparison of the data derived from reading to that from speech show:-

- All subjects, (except subject 39) used comparable or higher mean Fo values when reading than when speaking.
- The Fo values derived from reading are higher than the values derived from speaking for most subjects, (10). The exceptions were subjects 23, 30 and 37, (one value), and subjects 34 and 39 (both values of the range).

Subj. No	Age (years)	Material	Frequency Value Mean	Lowest	Highest	Subj. No	Age (years)	Material	Frequency Value Mean	Lowest	Highest
29	9.12	R	212	181	260	23	9.49	R	221	198	267
		Sp	194	166	233			Sp	206	174	272
25	9.14	R	247	213	324	34	9.73	R	265	242	315
		Sp	229	203	277			Sp	269	244	333
39	9.28	R	257	221	317	26	9.78	R	239	211	284
		Sp	273	249	331			Sp	212	198	249
33	9.3	R	253	225	307	27	9.79	R	262	221	335
		Sp	226	201	265			Sp	255	217	319
36	9.38	R	249	200	322	30	9.79	R	232	218	274
		Sp	224	191	271			Sp	231	205	289
32	9.39	R	246	214	315	37	9.8	R	273	236	334
		Sp	231	210	270			Sp	262	238	319
38	9.48	R	231	208	297	40	9.99	R	329	277	407
		Sp	213	197	244			Sp	285	255	367

Table 23 Data derived from reading and speech for subjects age 9 years:- mean Fo,and the lowest and highest Fo of the range.

9.4.2 *Fo Data - Speech*

The range of Fo, from the lowest of the low values (166 Hz) to the highest of the high values (367 Hz) is 14.6 S/T.

The difference between the lowest and highest of the low values (166 Hz – 256 Hz) is 7.5 S/T; the difference between the lowest and highest of the high values (233 Hz – 367 Hz) is 8.7 S/T. The same subjects used the lowest low and high Fo, and the highest low and high Fo as found in the reading samples.

- Most subjects (the exception are subjects 23, 34 and 30), used a narrower Fo range in speech than in reading. (These subjects used a narrower average range than their peer group when reading which may be related to a lack of confidence reading).

Material	Average Values	Subject no. 23	34	30
Reading	6	5.1	4.5	3.9
Speech	5.4	7.7	5.3	5.9

Table 24 Comparison of Fo ranges in S/T derived from reading and speech for 3 subjects age 9 years.

- Comparison of mean Fo (speech) at ages 8 years and 9 years for five subjects shows a lowering in the mean Fo for three subjects, (subj 33: 1.S/T; subj 37: 0.88 S/T; subj 38: 0.2 S/T) Two used a higher mean Fo; (subj 34: 2 S/T; subj 39: 0.74 S/T).

It is evident that useful information can be deduced from average Fo, by age group to provide comparisons between age groups, in relation to different materials, and to identify trends.
In view of the potential for pertinent individual differences it is relevant to inspect data by presentation of the data for individuals within each age group, (as above); this enables identification of individuals whose voice use differs notably from their peer group for further investigation; as well as comparison of group averages.

9.5 *Subjects age 10 years*

The mean Fo values derived from reading span 6.9 S/T, from 197Hz to 295Hz. Although the value for subject 20 appears conspicuous, the actual difference between the mean Fo of 295 Hz and the next highest value, (subject 15: 275Hz) is merely 1.2 S/T; subject 20 is 7.56months older than subject 15.

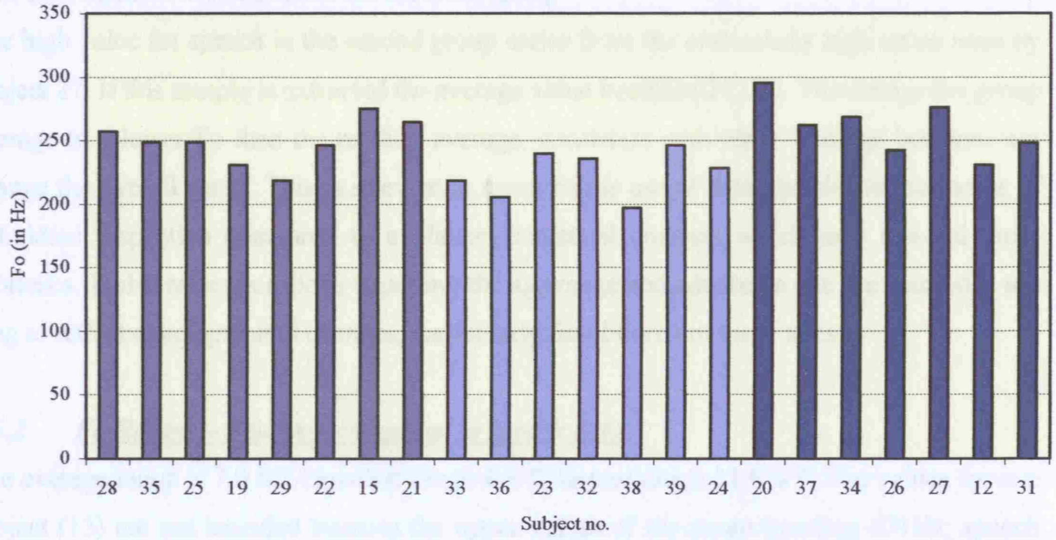


Fig 8 The mean Fo. values derived from reading for subjects age 10 years shown in ascending age order from left to right:
subjects 28–21 ages 10-10.29years.
subjects 33-24 ages 10.3-10.5years.
subjects 20-31 ages 10.6-10.9years.

The mean Fo values derived from speaking differ by 7.2 S/T, from the lowest value of 180Hz to the highest value of 273Hz.show that these subjects 20 and 15 are not distinguished from the group. The lowest value 180Hz (subject 38) is 5.3 lower than the group average of 245Hz.

9.5.1 *Comparison of mean Fo for reading and speech*

Interpretation of the average values for each group is limited, but it is noted that if this group is divided (10-10.48years and 10.5-10.9years) the average of values for the older group is slightly higher than those for the younger group; (reading 1 S/T, speech 2.2 S/T).

Material	Age (in years)		
	10 - 10.97	10 - 10.48	10.54 - 10.97
Reading	245	238	252
Speech	240	229	261

Table 25 The average of the mean Fo values derived from reading and speech for the 10 year age group compared to the average for subjects in six month age bands.

The values become marginally higher for the younger group (10 – 10.48years), if the sample for subject 38, who uses a lower than average Fo is extracted; (reading 241Hz and speech 235 Hz), but remain lower than those for the older group.

The high value for speech in the second group arises from the particularly high value used by subject 27. If this sample is extracted the average value becomes 242Hz. This brings the group average to a lower Fo than the reading average, consistent with other findings but does not change the overall result. This is relevant in terms of the use of data and shows the merits of individual inspection compared to a blanket statistical analysis which may conceal these subtleties. It also raises questions regarding the age range and whether a one year period is too long to reflect developmental changes, particularly for children of these ages.

9.5.2 *Fo Range – Reading compared to speech data.*

The average range is 7.0 S/T (smallest range 4 S/T; largest range 11.5 S/T).The values for one subject (15) are not included because the upper values of the range (reading 471Hz; speech 460Hz) resulted from spurious outlying frequencies and distort the range used; however inclusion of this data only increases the average S/T range by 0.1S/T.

The difference between the lowest and highest of the low Fo range values is 8.8 S/T (169Hz – 281Hz).

The difference between the lowest and highest of the high Fo range values is 8.7 S/T (242Hz – 399Hz).

The values for the younger age group are closer to those for the whole group, and the values for the older group are higher than the average for the whole group.

	Age Groups (in years)					
Average	10.01 - 10.48		10.54 - 10.97		10.01 - 10.97	
Values	Reading	Speech	Reading	Speech	Reading	Speech
Low	209	199	217	211	208	203
High	314	281	340	322	316	296
Semitone Range	7.05	6	7.63	7.12	7.22	5.3

Table 26 Comparison of the average values for the lowest and highest Fo in six month age groups, (10.01–10.48yrs and 10.54–10.97 years), with the average for the entire age group, (10.01 –10.97years)

The mean, mode and median Fo values are all close with the exception of the values for subjects 29 and 12 (speech) and subjects 15, 23, 20, 26, and 27 (reading).

Subject	29	12	23	20	26	27	15
Hz	31	34	16	30	47	33	25
S/T	2	2.5	1.2	1.8	3.1	2.2	1.6

Table 27 The difference between mean and mode values (in Hz and S/T) for seven subjects.

There are three subjects of exactly the same age in this group, (10.48years); comparison reveals a difference of 3.8 S/T and 5.3 S/T in the mean values for reading and speech respectively, and a difference of 0.7 S/T, and 3.4 S/T between the range in reading and speech.

Subj. No	Material	Mean Fo	Fo Range		
			Low	High	Semitones
39	Reading	246	224	306	5.4
32		236	208	301	6.3
38		197	169	241	6.1
39	Speech	244	230	284	3.6
32		222	188	281	6.9
38		180	167	206	3.5

Table 28 The difference in Fo values (mean, lowest and highest of the Fo range and S/T range) for subjects of exactly the same age, (10.48years).

However, if the Fo used by subject 38 is compared to the average values of subjects 39 and 32 it gives an indication of the extent of variation between boys of the same age, and raises the question of the relevance of that to the vocal demands upon them.

	Reading		Speech	
	Fo Range			
	Low	High	Low	High
Average of values for subjects 32 and 39	216	304	209	282
subject 38	169	241	167	206
Semitone Difference	4.25	3.99	3.82	5.46

Table 29 Comparison of Fo range values of selected subjects

9.6 *Fo Data for Subjects age 11 years*

The mean Fo values derived from reading for this age group vary from 181Hz to 290Hz (8.1S/T); the lowest mean Fo derived from speech is 175Hz compared to the highest value of 286Hz (8.5S/T).

Data is presented for (i) subjects aged 11years at the time of their first recording, (mean Fo and Fo range), and (ii) subjects who were recorded at ages 10years and 11 years.

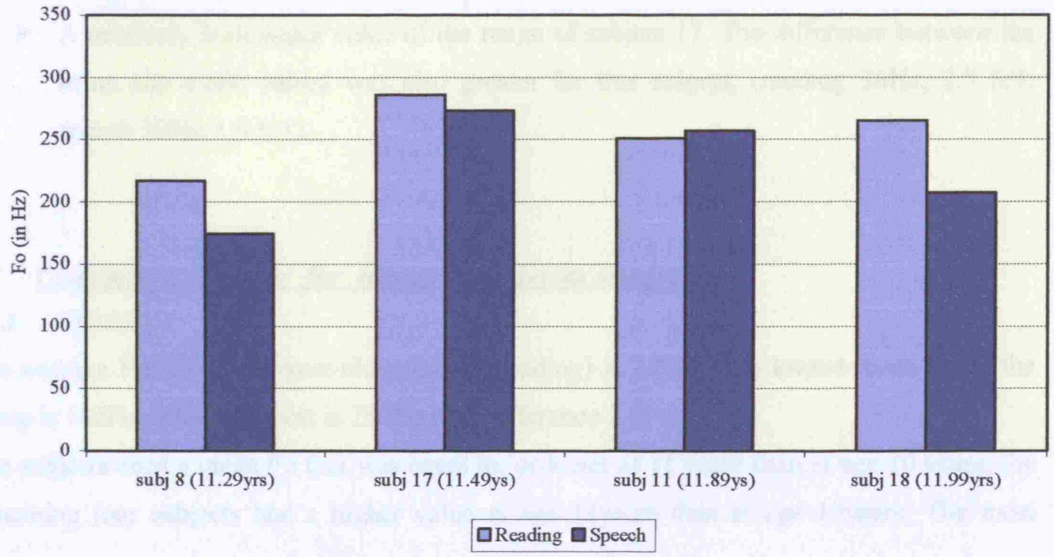
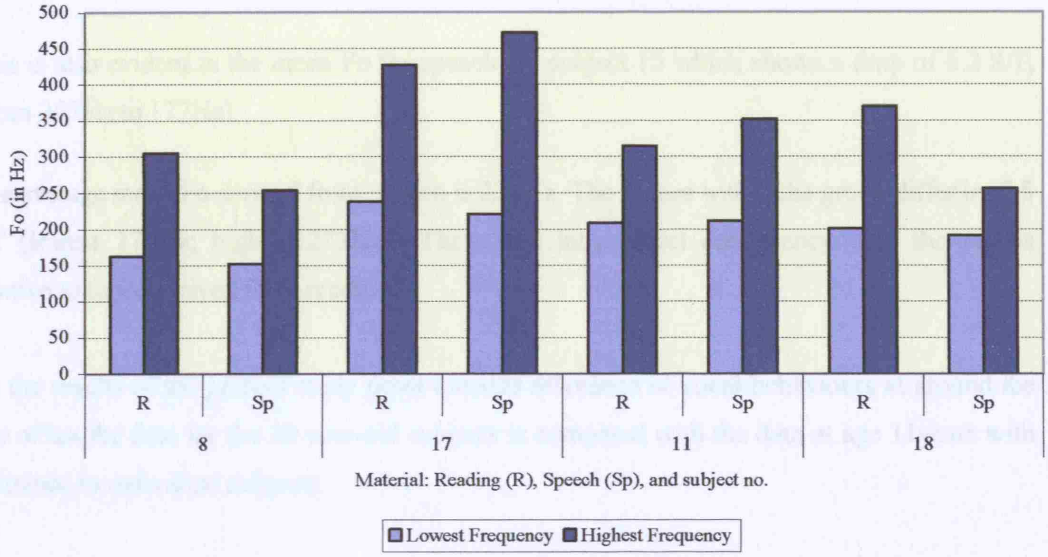


Fig 9 Mean Fo derived from reading and speech for four subjects age 11 years



Subject	8	17	11	18
S/T range (R)	10.9	10	7.1	10.6
S/T range (Sp)	8.8	13	8.8	5

Fig 10 The lowest and highest values of the Fo range derived from reading (R) and speech (Sp) for 4 subjects age 11years, with the subject age and S/T range.

These results show:-

- A relatively low value at the low end of the range for both the reading and speech samples of subject 8.
- A relatively high upper value of the range of subject 17. The difference between the mean and mode values was also greater for this subject, (reading 36Hz, 2.3 S/T: speech 30Hz, 1.9 S/T).

9.7 *Comparison of results for 10-year and 11-year age groups*

9.7.1 *READING*

The average Fo for the 11-year-old subjects (reading) is 240Hz; the lowest mean Fo in the group is 182Hz and the highest is 282Hz (S/T difference 7.6)

Ten subjects used a mean Fo that was equal to, or lower at 11 years than at age 10 years; the remaining four subjects had a higher value at age 11years than at age 10years. The most conspicuous differences are shown by subjects 15 and 21 with a drop of 5 S/T and 6.5 S/T respectively; (Subject 15. 275Hz – 206Hz; Subject 21 265Hz – 182Hz).

This is also evident in the mean Fo for speech for subject 15 which shows a drop of 6.2 S/T, (from 253Hz to 177Hz).

The average mean Fo derived from speech is 222Hz. The values within the group differ by 7.5 S/T (lowest 177Hz; highest 273Hz) There was intrasubject consistency with the values relative to those derived from reading.

As the results of the present study point towards relevance of vocal behaviours at around the age of ten the data for the 10-year-old subjects is compared with the data at age 11years with reference to individual subjects.

9.7.2 *Comparison of the lowest Fo of the range between tasks at age 10years and 11 years.*

Subj No.	Age (years)	Age Interval (months)	Material	Change to lowest frequency in semitones		Change to highest frequency in semitones		Change to total range in semitones	
				Higher	Lower	Higher	Lower	Increased	Reduced
25	11.02	10.8	R	0.7		1		1.7	
			Sp		0	2.6		4.2	
27	11.12	0.4	R		0.6		1.1		1.5
			Sp		0.1		0.6		1.5
28	11.12	13.32	R		1.3		1.7		0.3
			Sp		2.3	1.5			0.7
15	11.15	10.32	R	8.8			7.8	0.9	
			Sp	2.1			14.3		12.1
19	11.15	11.4	R	0.7		3.2		2.4	
			Sp		0.1		0.4		0.6
29	11.22	12	R	0.5			0.3		0.8
			Sp	0			0.4		0.5
22	11.3	12.07	R		0.8	5		5.7	
			Sp		6	4.3		10.3	
21	11.34	13.2	R		5.2		7.9		2.6
			Sp		0.4	1.3		1.9	
36	11.41	12.02	R		0.4		1.9		1.5
			Sp		0.1		2.3		2.2
24	11.42	10.56	R		0.1		0.8		0.7
			Sp	0.8		0.1			0.7
20	11.58	11.28	R		2		4.1		2.1
			Sp	1.6			4.4		2.9
12	11.81	11.76	R	1.8		1.9		2.6	
			Sp		0.3		6.9		6.3

Table 30 Changes in the Fo ranges used in reading (R) and speech (Sp) between the ages of 10 years and 11 years. The interval between the recordings is shown in months. The direction of variation (higher or lower), at either end of the range, and the difference in the total range is shown in S/T.

This shows:-

- Lower values at both the low and high ends of the range for reading and speech.(3 subjects).
- A lower value at the low end of the range in reading and speech, (4 subjects).
- Lower values at the low end for one of the materials, (4 subjects).
- A lower high value in reading, (5 subjects)
- A lower high value in speech, (2 subjects)

Whilst again this is not conclusive because of the small number of subjects, it does reveal a downward trend beginning at this stage.

9.7.3. *COMMENTS ON INDIVIDUAL SUBJECTS*

Subject 12: A rise in the Fo derived from reading. This may reflect more expressive reading, associated with more confidence in both reading skills and the familiarity of the procedure.

Subject 19: A rise in the Fo derived from reading and a minimal rise in speech.

Subject 27: A lowering of both the low Fo and the upper Fo values with a smaller Fo range at 11 yrs than at 10yrs.

Subject 28: A lowering of the low Fo and of the upper Fo in reading, (but not in speech) with a smaller Fo range.

Subject 29: A higher Fo at the lower end of the range, with a lower Fo at the upper end and a smaller Fo range.

9.8 *Data for subjects age 12 years.*

9.8.1 *MEAN Fo READING AND SPEECH*

The mean Fo values range from the lowest of 171Hz to the highest, 270 (a difference of 7.8 S/T; group average mean Fo 222Hz).

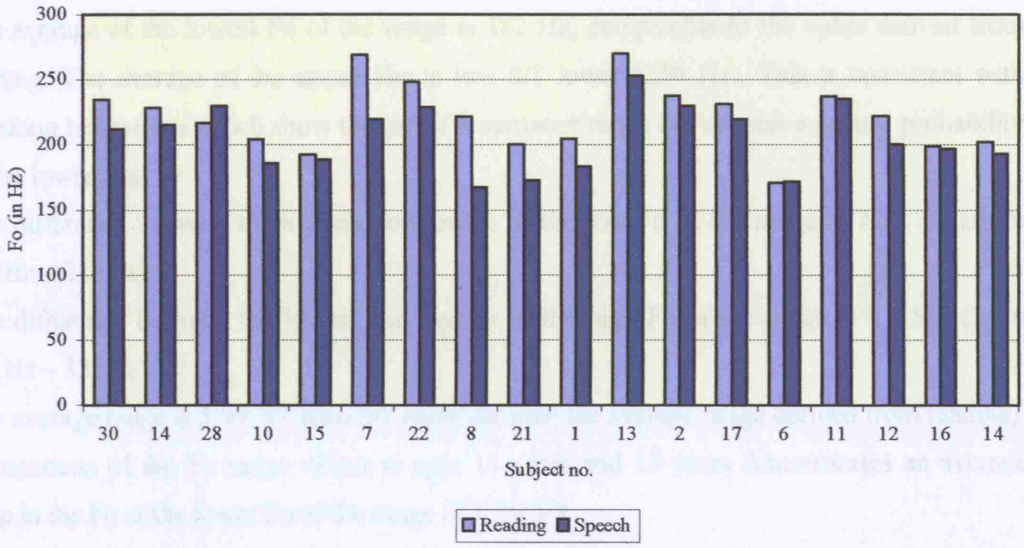


Fig 11 Mean Fo derived from reading and speech for subjects age 12 years shown in ascending age order, (from left to right).
Subjects 30 – 7 : age range 12 – 12.18yrs.
Subjects 22 – 13: age range 12.27 – 12.48yrs
Subjects 2 – 6: age range 12.58 – 12.75yrs
Subjects 11 – 14: age range 12.85 – 12.91yrs

Removal of either data set for subject 14 did not affect the average mean for this group. Lower values, (below 200Hz), are used by subjects 15.21 and 6. When this is compared to the mean Fo derived from speech it demonstrates that all the subjects except subjects 28 and 6 used a lower mean Fo in speech than when reading, (although the difference for subject 6 is negligible, (1.0Hz: 0.1 S/T), however a mean Fo lower than 200Hz was used in speaking by subjects 10, 15, 8, 21, 1 and 6.

9.8.2 *Fo ranges for 12-year age group*

Inspection of the Fo ranges used is more revealing.

9.8.2.1 *READING*

The average values for this age group are:-Lowest Fo- 182Hz.: Highest Fo - 291Hz: Range – 7.9 S/T

The low Fo values range from 148Hz – 220Hz; a difference of 6.8 S/T

The high Fo values range from 209.5Hz – 357Hz; a difference of 9.23 S/T..

The average range is 7.99 S/T; (smallest range 5.89 S/T; largest range 13 S/T).

9.8.2.2 *SPEECH*

The average of the lowest Fo of the range is 182 Hz, comparable to the value derived from reading. The average of the upper Fos is two S/T lower (259 Hz). This is consistent with speaking behaviours which show the use of a narrower range of Fos with a greater probability of the lower Fos.

The difference between the highest and lowest of the low Fo of the range is 7.32 S/T (from 142Hz – 216Hz)

The difference between the lowest and highest of the high Fo of the range is 8.2 S/T (from 202Hz – 325Hz)

The average range is 5.99 S/T (two S/T narrower than the average range derived from reading)

Comparison of the Fo range values at ages 11 years and 12 years demonstrates an average drop in the Fo at the lower Fo of the range of 1.76 S/T.

These results would suggest that the lower Fo of the range is a useful value to monitor.

Subj No	Age Interval	Material	Difference in low Fo of range		Difference in high Fo of range	
			Hz	Semitones	Hz	Semitones
8	0.99	R	4	0.4	35*	1.8*
		Sp	10	1.2	42	2.6
11	0.96	R	22	1.9	9	0.5
		Sp	3	0.3	68	3.7
12	1.06	R	25	2	52	2.8
		Sp	15	1.4	34	2.4
15	0.99	R	11	1.1	42	2.6
		Sp	3	0.2	60	4.5*
17	1.18	R	53	4.3	116	5.5
		Sp	33	2.7	177	8.1
21	0.95	R	1*	0.1	31*	2.2*
		Sp	20	2.1	34	2.5
22	0.97	R	8	0.7	62	2.9
		Sp	40*	3.8*	118	6.1
*denotes values higher at age 12yrs than at age 11yrs						

Table 31 The difference between the lowest and highest values of the range derived from reading and speech at ages 11 years and 12 years shown in Hz and S/T.

The usefulness of comparison of group averages derived from a small sample is debatable; it warrants comment that values for three of the four parameters are close; however, one value, (highest Fo reading) differs sufficiently to demonstrate the limitation of using group data.

The average difference in the low Fo between the ages of 11 years and 12 years is 1.5 S/T (reading), and 1.1 S/T (speech). The high Fo of the range lowered by 1.4 S/T (group average) in reading and 3.5 S/T in speech.

9.9 *Data for subjects age 13 years*

There are four subject in this age group:-.

Subject no:	4	18	8	17
Age (in yrs):	13.08	13.16	13.28	13.42

All subjects demonstrate the use of mean Fo below 175Hz. and a mean Fo for speech typically lower than the reading Fo.

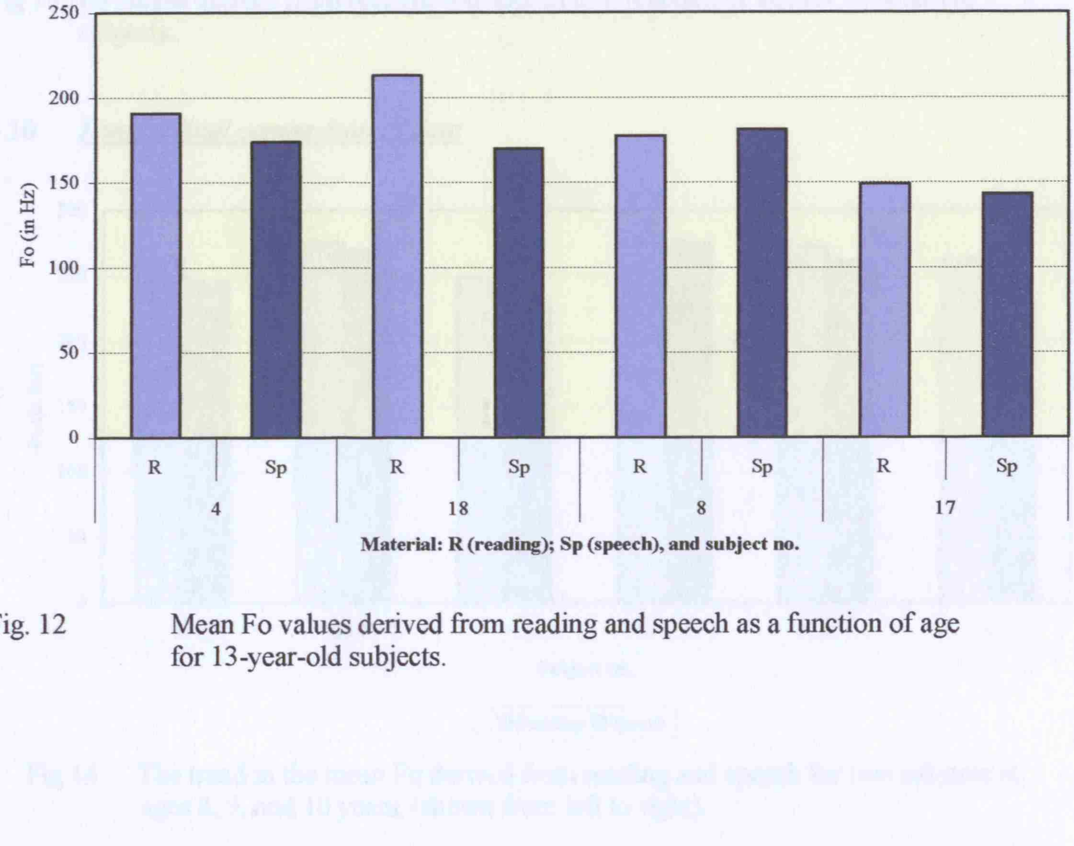


Fig. 12 Mean Fo values derived from reading and speech as a function of age for 13-year-old subjects.

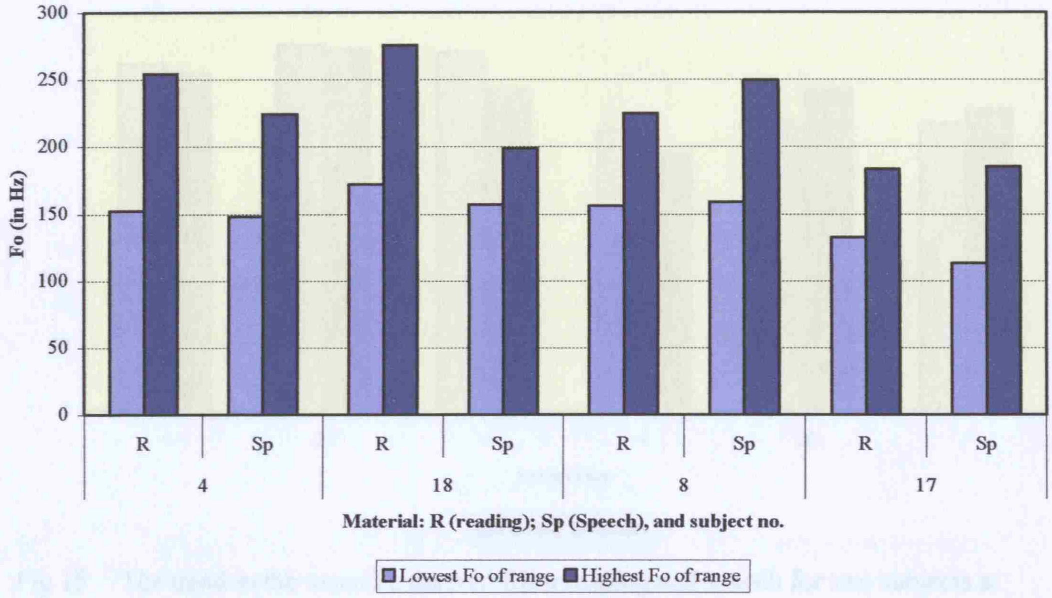


Fig 13 Fo ranges derived from reading and speech as a function of age for 13-year-old subjects.

9.10 *Longitudinal comparison of data*

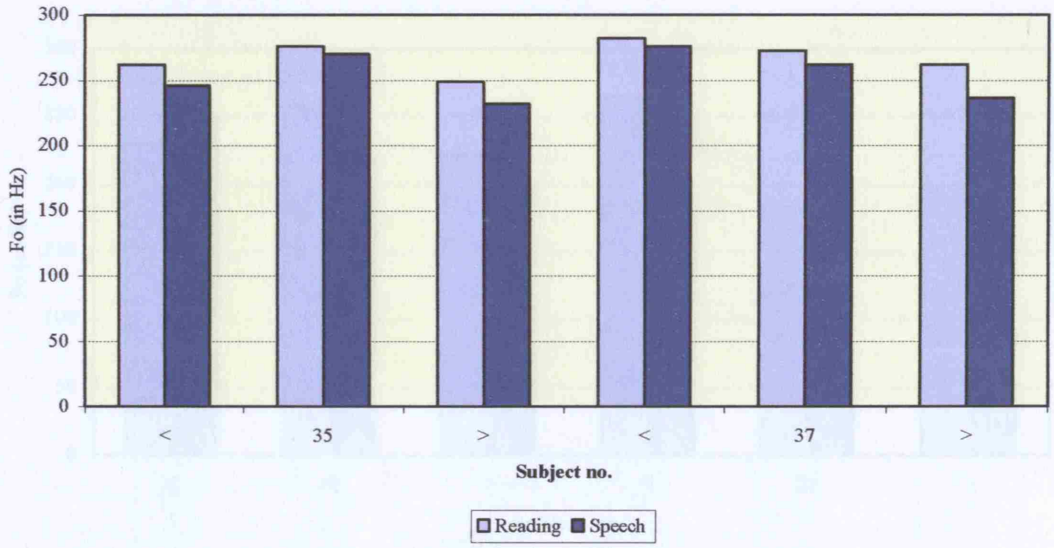


Fig 14 The trend in the mean Fo derived from reading and speech for two subjects at ages 8, 9, and 10 years, (shown from left to right).

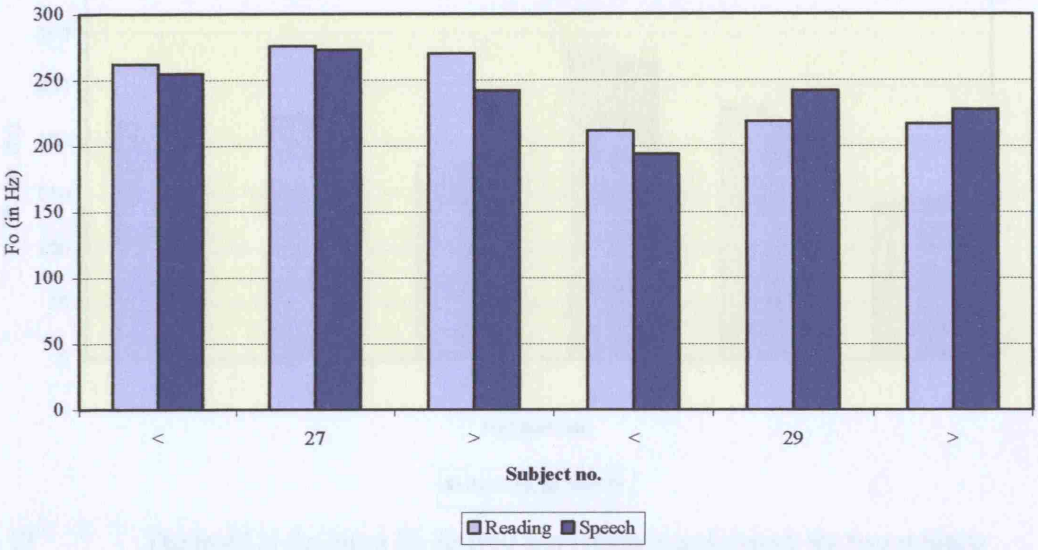


Fig 15 The trend in the mean Fo derived from reading and speech for two subjects at ages 9, 10 and 11 years, (shown from left to right).

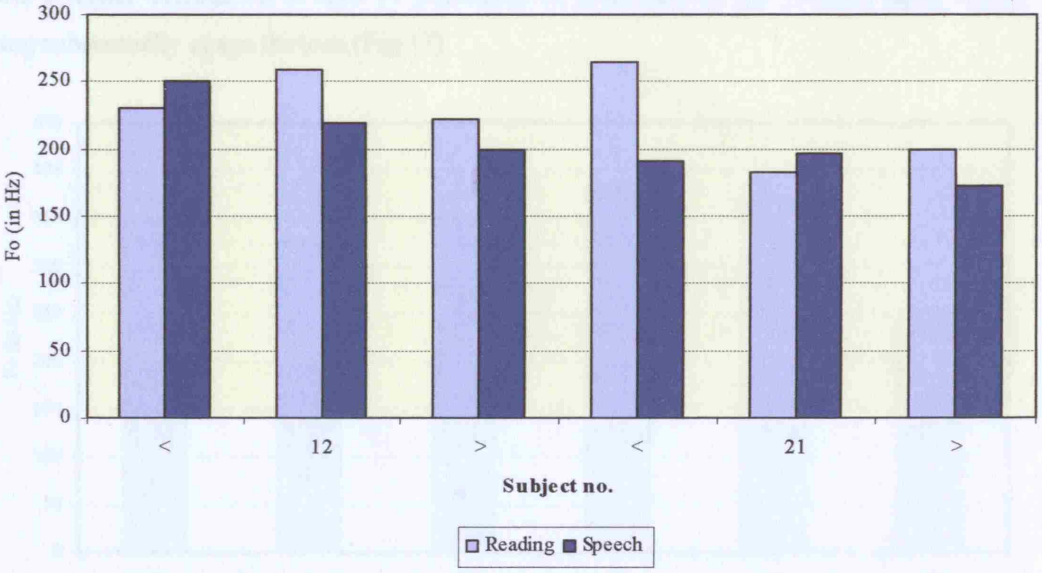


Fig 16 The trend in the mean Fo derived from reading and speech for two subjects at ages 10, 11 and 12 years, (shown from left to right).

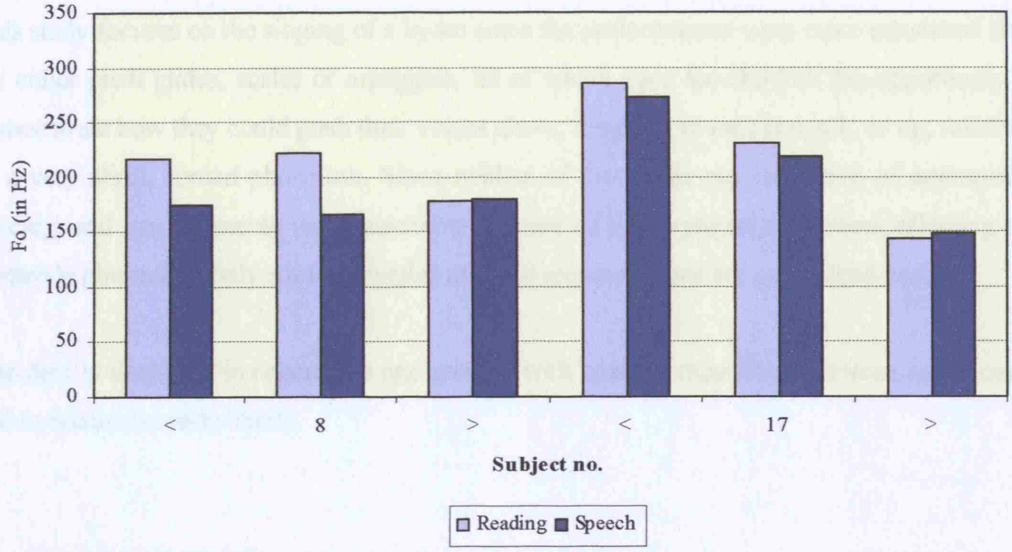


Fig 17 The trend in the mean Fo derived from reading and speech for two subjects at ages 11, 12 and 13 years, (shown from left to right).

9.11 SINGING

The data derived from singing is presented separately from that derived from reading and speech although some comparisons may be useful, for example the trend derived from singing shows a higher average Fo at ages 11 years and 12 years than at the younger ages, before falling substantially at age thirteen.(Fig 17)

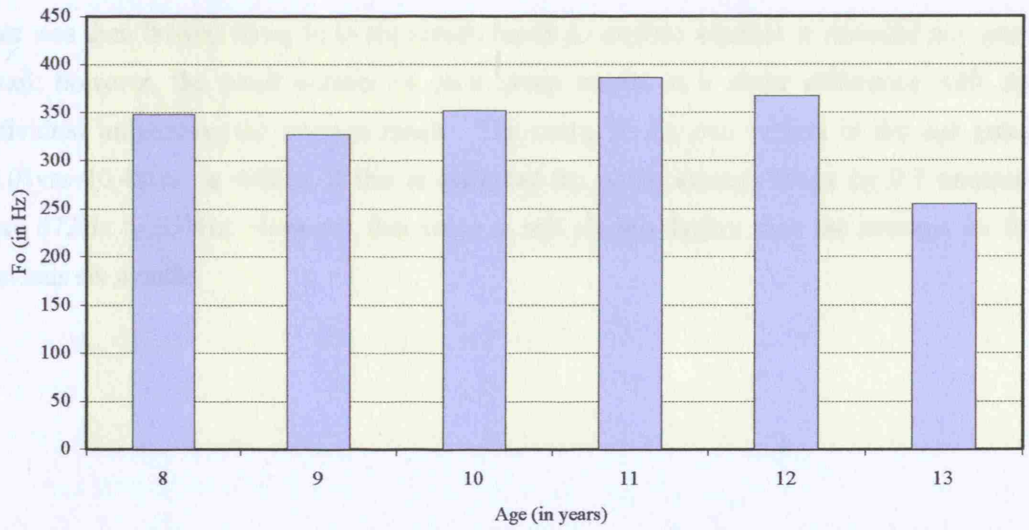


Fig 18 The average of the mean Fo values derived from singing as a function of age.

(Since the subjects were meant to be singing the same melody, in the same key, the values should, theoretically, be the same.)

This study focuses on the singing of a hymn since the performances were more consistent than for either pitch glides, scales or arpeggios, all of which gave the children the opportunity to demonstrate how they could push their voices down, resulting in excess creak, or up, resulting in a very shrill, forced phonation. Since neither of these was representative of appropriate voicing, and measurements were unreliable because of the laryngeal movement affecting the electrode placement, only some examples of these measurements are considered usable.

The data is inspected in relation to age groups, with some comparisons between age groups, and in relation to individuals.

The average mean Fo values demonstrated:-

- A minimal drop in the average mean Fo from the eight-year-old group (348Hz) to the nine-year-old group (327Hz), a difference of (1 S/T).

- A rise in the average mean Fo from nine years (327Hz) to eleven years.(386Hz), (a difference of 2.8S/T).

- A conspicuous drop in the mean Fo from the twelve-year-old group (367Hz) to the thirteen-year-old group, (255Hz), a difference of 6.3 S/T).

This was then broken down in to six month bands to explore whether it revealed any more detail; however, the small number in each group results in a slight difference with one individual influencing the average result. The mean Fo for one subject in the age group 10.01yrs–10.48yrs is 498Hz; if this is extracted the group average drops by 0.7 semitone from 372Hz to 356Hz. However, this value is still slightly higher than the average for the previous six months.

9.11.1 8-year age group

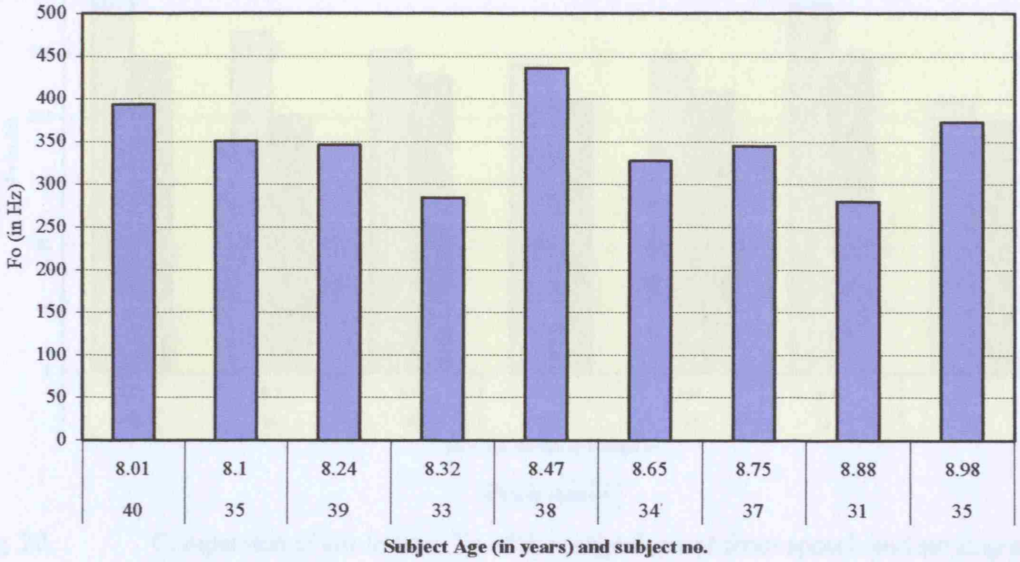


Fig 19 Mean Fo values derived from singing as a function of age. (subjects age 8 years)

The range of mean Fo values in this group is from 280Hz to 436Hz; this latter value is 3.8 semitones higher than the group average mean Fo.

The subjects all sang the same hymn and were meant to sing it in the same key, at the same pitch; the different ranges demonstrate that this did not happen. This may reflect the level of singing skill and the difference in singing without either a target stimulus or accompaniment, (instrumental or choral).

The average S/T range is 9.2 S/T, but the individual ranges differ from 5.8 S/T to 11.2 S/T. The low values of the range differ by 7.3 S/T (214Hz – 326Hz: average 269Hz); the high values of the range differ by 9.2 S/T (338Hz – 576Hz: average 466Hz).

Anecdotal evidence suggests that singing training with these children concentrates more on the upper pitches and register transitions, than on the lower notes. The perceptual evaluation of these subjects identified some subjects who appeared to be straining to reach the lower notes and it may be argued that taking account of both the physical differences between children and adults, and the questionable appropriateness of applying techniques learnt by adults to children, this aspect is equally important.

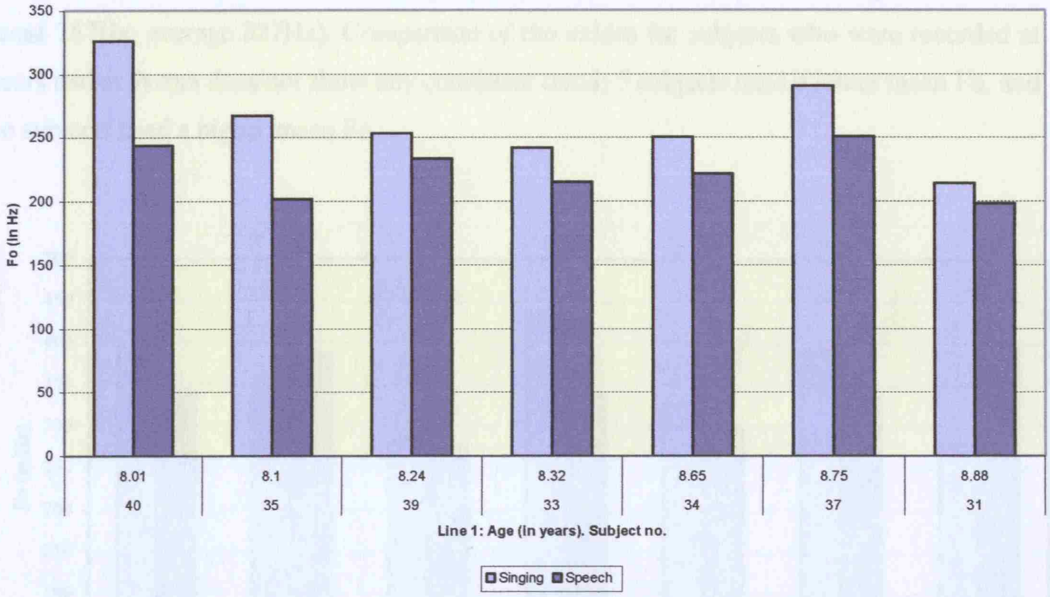


Fig. 20 Comparison of the lowest Fo of the range derived from speech and singing in the 8-year-old group.

9.11.2 9- year age group

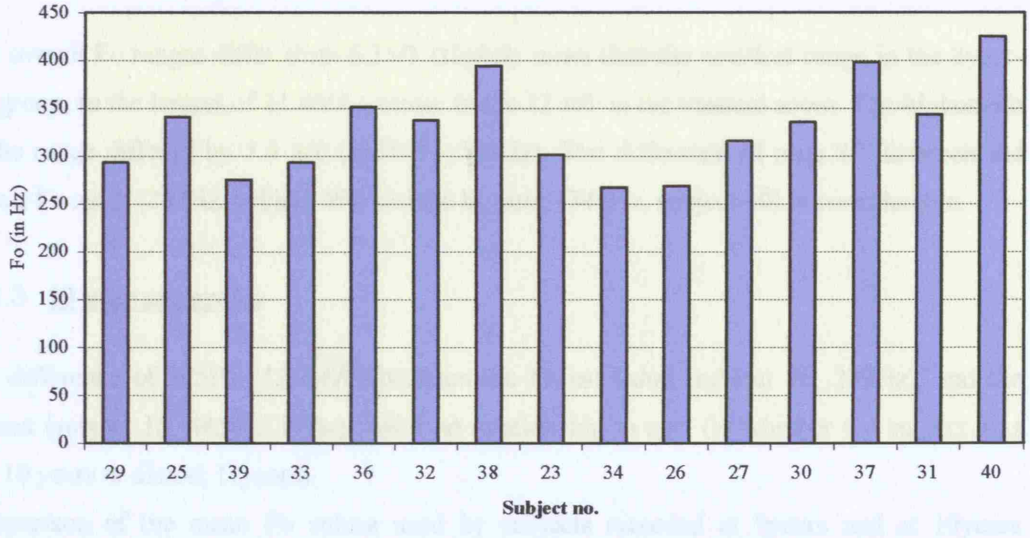


Fig. 21 Mean Fo derived from singing as a function of age. Subjects age 9years shown in ascending age order (from left to right).
Subjects 29 – 23: Age range 9.12years – 9.49years
Subjects 34 – 40: Age range 9.73years - 9.99years

The variation in mean Fo within this age group is considerable, (6.8 S/T; highest 398Hz – lowest 267Hz; average 327Hz). Comparison of the values for subjects who were recorded at 8years and at 9years does not show any consistent trend; 5 subjects used a lower mean Fo, and two subjects used a higher mean Fo.

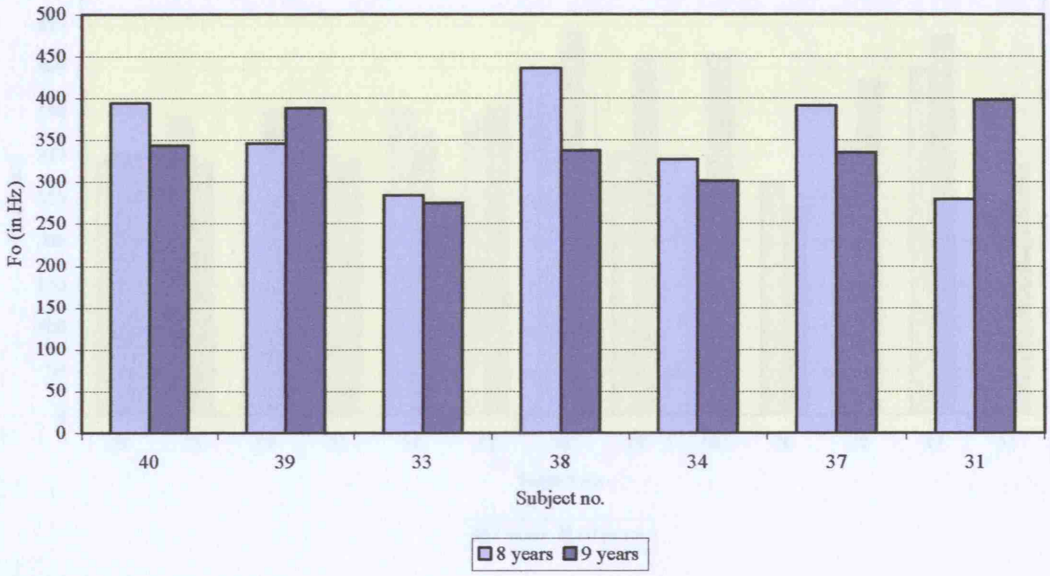


Fig 22 Mean Fo derived from singing for subjects at age 8years and 9 years.

The overall Fo ranges differ from 6.1S/T (slightly more than the smallest range in the 8year-old group, to the largest of 11.4S/T – closer to the 12 S/T in the musical score. The highest Fo of the range differed by 7.5 S/T (355Hz – 551Hz). The difference of nine S/T between the lowest Fo used, (207Hz. subject 39), and the highest, (348Hz, subject 40) is considerable.

9.11.3 <u>10-year age group</u>

The difference of 245Hz (12.2 S/T) between the lowest value (subject 26, 239Hz), and the highest (subject 15, 485Hz) is large with no relationship to age, (ie whether the subject was just 10 years or almost 11years).

Comparison of the mean Fo values used by subjects recorded at 9years and at 10years illustrates that for ten of the subjects the mean Fo is higher at 10years than at 9 years; three subjects used a lower Fo, (subject 36 (10.39yrs); subject 26 (10.77yrs) and subject 31 (10.97 yrs)).

This raises two questions:-

- Are the higher values the result of vocal training?
- Are the lower values indicative of voice change associated with maturation?

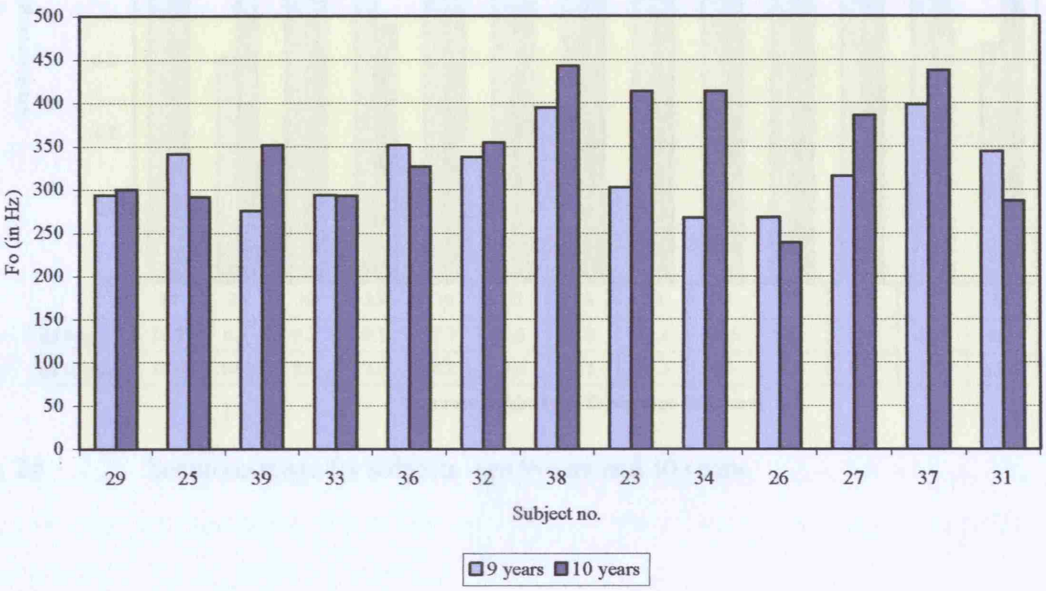
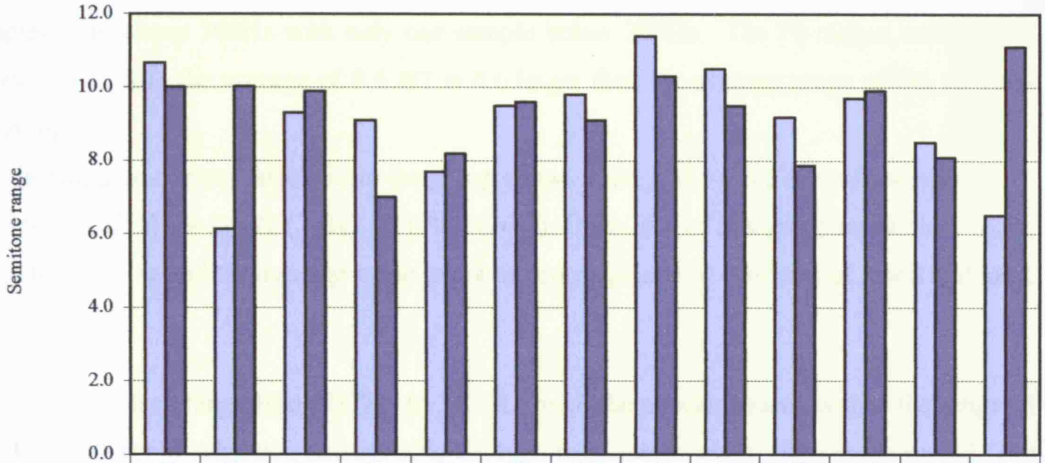


Fig. 23 The mean Fos derived from singing in subjects at age 10 years compared to the value at age 9 years.

The average Fo range is 9.43 S/T; comparable to the average range of both the 8-year-old and 9-year-old group. The low Fos values are between 194 Hz and 391Hz, (197 Hz:12 S/T); the high Fos are from 596Hz down to 306Hz, (289Hz: 11.5 S/T). The difference between the narrowest range and the widest range is 4.9 S/T.

Comparison of the Fo range in subjects recorded at 9years and 10years shows that the low Fo value was higher at age 10years than at age 9years in nine of the thirteen subjects, and that the high Fo value was equal or higher in eight subjects. Four subjects showed a lowering of both the low Fo and the high Fo values (subjects 25, age 10.12yrs; 36,10.39yrs; 26, 10.77yrs; 31, 10.9yrs) and subject 33 used a higher low Fo and a lower high Fo resulting in a narrowing of the Fo range from 9.1 S/T at 9yrs to 7 S/T at 10yrs. Although an increase in the overall Fo range may be relevant, no conclusions can be drawn for those subjects who had a lower values for both the low and high end of the range at age 10years compared to age 9years because this will be influenced by the pitch they started to sing on.



	29	25	39	33	36	32	38	23	34	26	27	37	31
9years	10.7	6.1	9.3	9.1	7.7	9.5	9.8	11.4	10.5	9.2	9.7	8.5	6.5
10years	10.0	10.0	9.9	7.0	8.2	9.6	9.1	10.3	9.5	7.9	9.9	8.1	11.1

Top row:Subject no. Table: Age (in years)

Fig 24 Semitone range for subjects age 9years and 10 years.

9.11.4 11- year age group

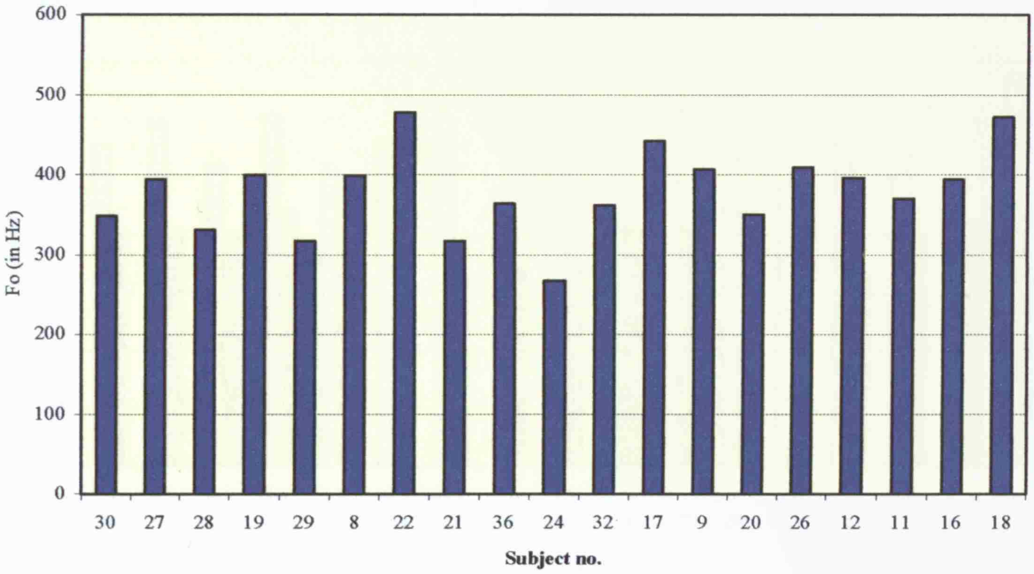


Fig 25 Mean Fo derived from singing as a function of age, subjects age 11years shown in ascending age order (from left to right).
Subjects no. 30 – 29 Age range 11.09 – 11.22years
Subjects no. 8 - 32 Age range 11.29 - 11.48years
Subjects no. 17 – 26 Age range 11.49 – 11.69years
Subjects no. 12 – 18 Age range 11.81 - 11.99years

The values ranged from 478Hz down to 268Hz, (average 386Hz), however 68% of the samples were above 360Hz with only one sample below 300Hz. The Fo ranges varied from 5.99S/T to 15 S/T; the average of 9.6 S/T is 0.6 larger than the average range of the 10-year-old group.

The distribution of range size within the group shows a range of <6 S/T (1% of subjects); 6 – 8.9 S/T (42%); 9-11 S/T (26%); >11 S/T (26%). Only 26% of this group came close to the range for the tune and the average value is not the consequence of extremes of small and large ranges.

The low Fo values range from 217Hz to 342 Hz, with the concentration within the range of 252Hz – 200Hz (11 subjects), compared to the high frequencies which show more spread. The values range from 341.6Hz to the highest of 815.6Hz, with most falling within the ranges of 400Hz to 500Hz (6 subjects), and 500-600Hz (8 subjects).

The Fo ranges vary from 5.99 – 15 S/T; average 9.6 S/T. Comparison of the low values to the mean Fo used in speech shows that this difference is more conspicuous compared to the relationship of these values in the eight year old subject group.

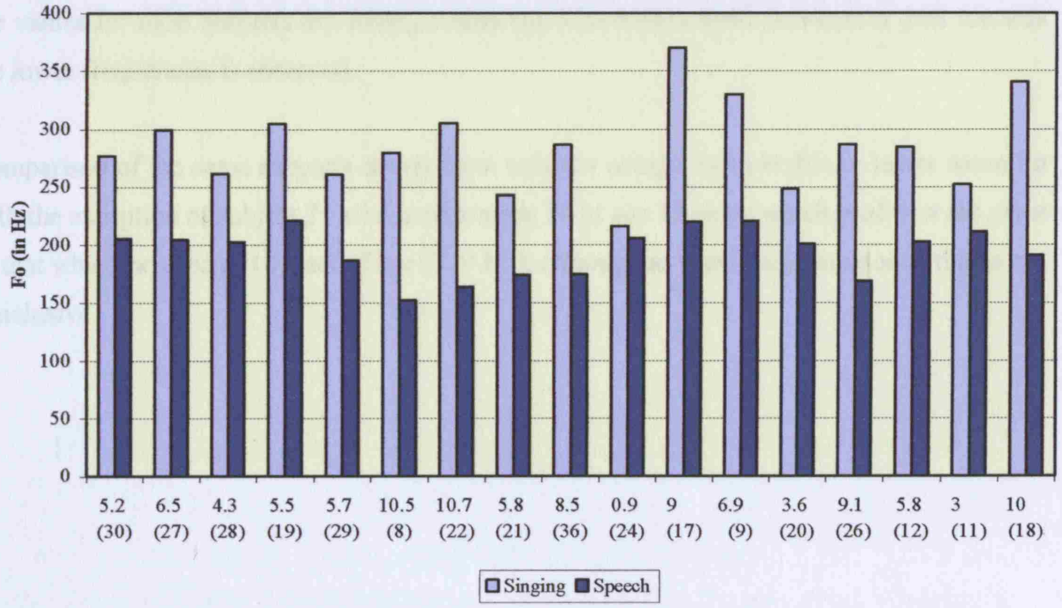


Fig 26 Comparison of the lowest value of the ranges derived from singing and speech of subjects at age 11 years. The difference is shown in S/T with the subject number given in brackets.

9.11.5 12-year age group

The average mean Fo for this group is 367; the mean Fo for one subject (14) is 172Hz (6.6 S/T) higher than the group average; if this value is extracted the group average is 361Hz. Because each group is made up of different subjects information resulting from comparisons is open to interpretation; however changes occurring to the group as a whole in terms of the distribution of mean Fo values are noted.

Mean Fo (Hz)	No. of subjects at each age.	
	11 years	12 years
< 250	0	2
< 300	1	2
300 - 350	4	2
350 - 400	8	6
400 - 450	4	5
> 450	2	1

Table 32 Distribution of samples according to mean Fo value in 50Hz bands

The number of subjects in each group is different, (11yrs–19 subjects; 12yrs–18 subjects) and the values for most subjects are falling within the 350–400Hz band, however a drift towards the lower frequencies is observed.

Comparison of the same subjects shows most subjects using a comparable or lower mean Fo with the exception of subject 21 who used a mean Fo at age 12 years which is almost the same as that which he used at 10years of age (379 Hz); although as previously mentioned this is not conclusive.

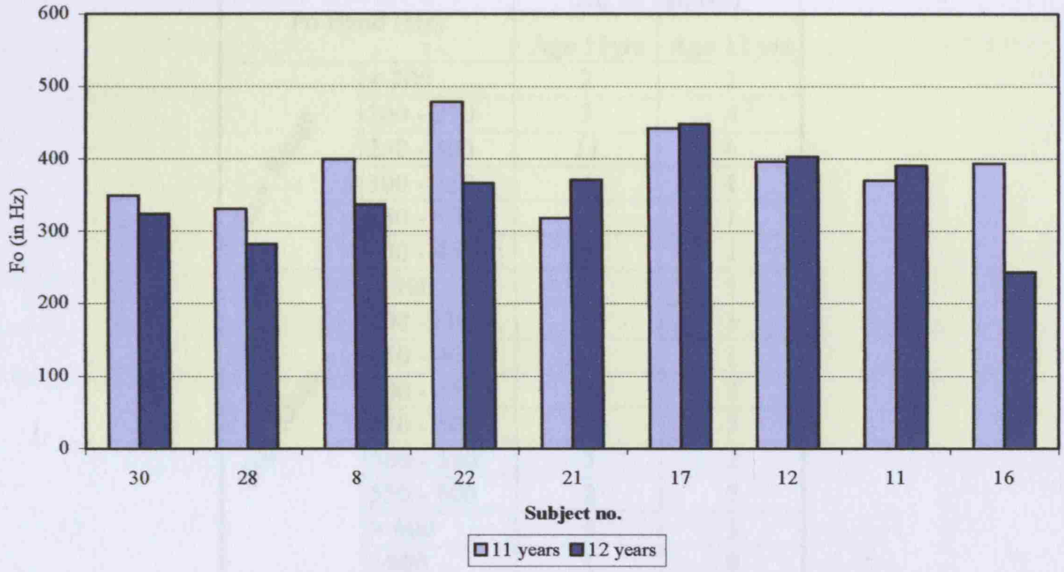


Fig 27 Comparison of the mean Fo derived from singing at ages 11years and 12 years

The Fo ranges show low Fo values between 185Hz and 438Hz, and the high Fos from 659Hz down to 270Hz, with an average semitone range of 9.8.

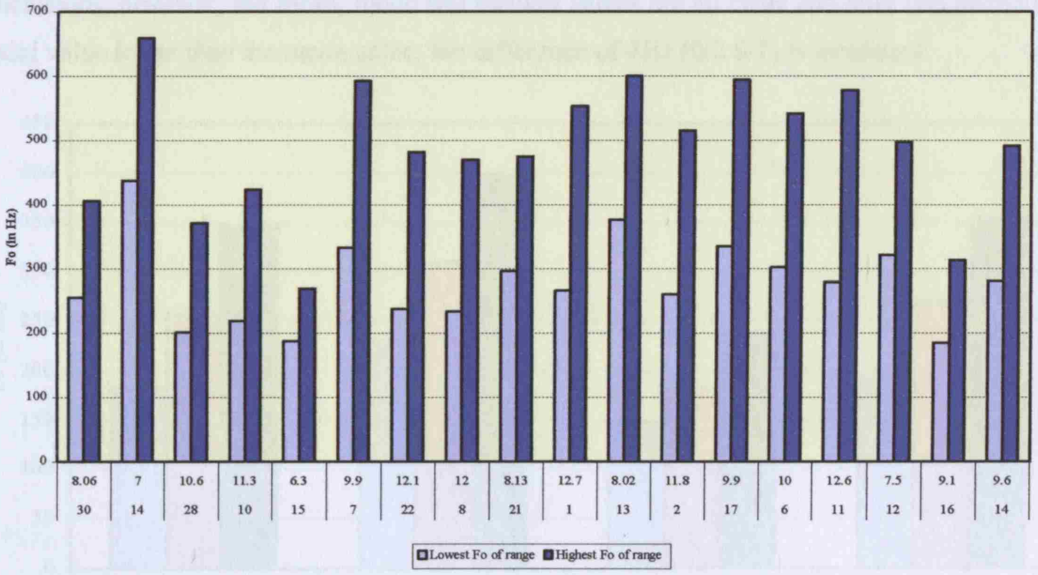


Fig 28 Frequency range derived from singing for subjects age 12 years shown in ascending age order(from left to right). The top row of figures is the S/T range; underneath are the subject nos.

Subjects 30 - 7	Age range 12 – 12.18years
Subjects 22 – 13	Age range 12.27 – 12.48years
Subjects 2 – 6	Age range 12.58 – 12.75years
Subjects 11 – 14	Age range 12.85 – 12.91years

Fo Band (Hz)		No. of subjects	
		Age 11yrs	Age 12 yrs
Low Range	< 200	2	2
	200 - 250	3	4
	250 - 300	11	6
	300 - 350	4	4
	350 - 400	1	1
	400 - 450	1	1
High Range	< 300	0	1
	300 -350	1	1
	350 - 400	2	1
	400 - 450	2	2
	450 - 500	5	5
	500 - 550	5	2
	550 - 600	2	5
	> 600	1	1
	>800	1	0

Table 33 Distribution of samples according to low and high values of Fo range

9.11.6 <u>13 year age group</u>

The number of subjects in the thirteen-year-old group is too small to allow any robust conclusions; however, the mean, mode and median values are all close and only one shows a modal value lower than the mean value; the difference of 4Hz (0.2 S/T) is incidental.

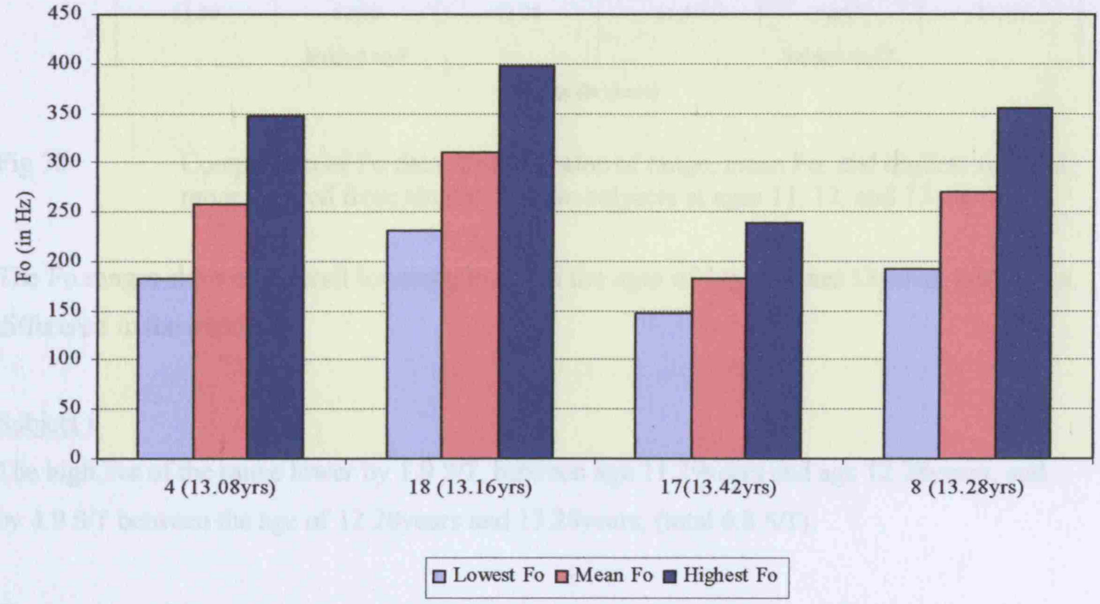


Fig 29 Fo data (lowest value of range, mean Fo and highest value of the range) derived from singing for subjects age 13 years.

There is a 7.7 S/T difference between the lowest and highest of the low Fo values, and 8.9 S/T between the lowest and highest of the high Fo values of the range. The inter-subject difference in the total ranges is 2.9 S/T. (11.2 S/T (subject no 4) – 8.3 S/T (subject no 17)).

9.12. LONGITUDINAL DATA: TWO SUBJECTS AT AGES 11.12 AND 13YEARS

Although four subjects were age 13 years were recorded two of them were in their last year at the Cathedral school at the start of the study and therefore there is only one data set for them. Subjects 8 and 17 were recorded at ages 11years and 12years and 13years and the data for these two subjects is presented.

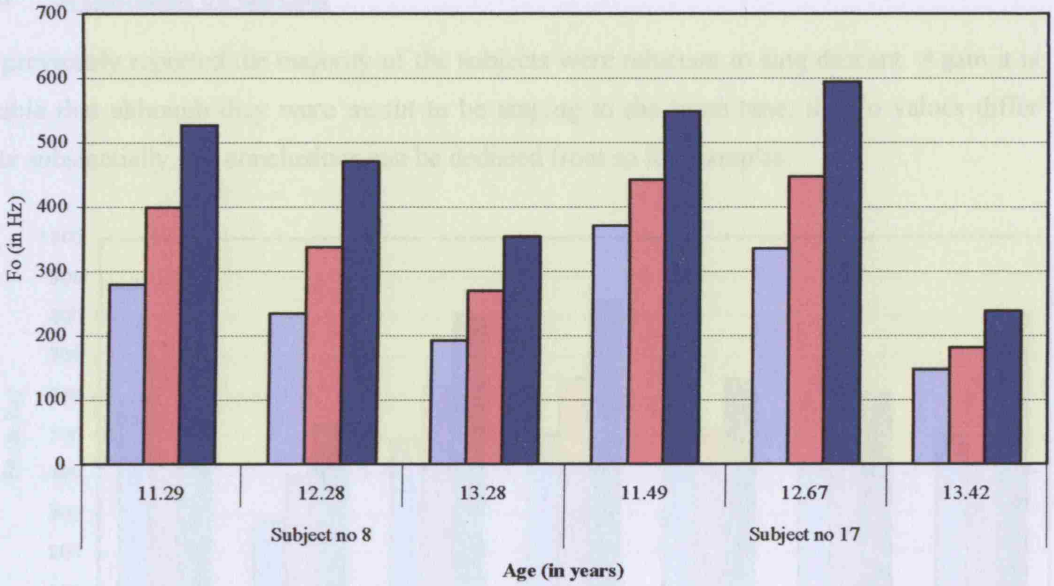


Fig 30 Comparison of Fo data, (lowest value of range, mean Fo. and highest value of range derived from singing for two subjects at ages 11, 12, and 13 years.

The Fo ranges show an overall lowering between the ages of 11years and 13years, but with a difference in the trends.

<u>Subject 8</u>

The high Fos of the range lower by 1.9 S/T, between age 11.29years and age 12.28years, and by 4.9 S/T between the age of 12.28years and 13.28years, (total 6.8 S/T).

The low Fos of the range lower by 3 S/T between age 11.29years and age 12.28years and by 3.37 S/T between age 12.28years and 13.28years, (total 6.4 S/T).

Subject 17

The high Fo of the range at age 12.67years is 1.3 S/T higher than at 11.49 years but then drops by 15.8 S/T between the age of 12.67years and 13.42 years.

The low Fos of the range drop by 1.7 S/T between the ages of 11.49years and 12.67 years and by 14.18 S/T between age 12.67years and 13.42years, (total 15.9).

9.13 A comment on descant

As previously reported the majority of the subjects were reluctant to sing descant. Again it is notable that although they were meant to be singing to the same tune, the Fo values differ quite substantially. No conclusions can be deduced from so few samples.

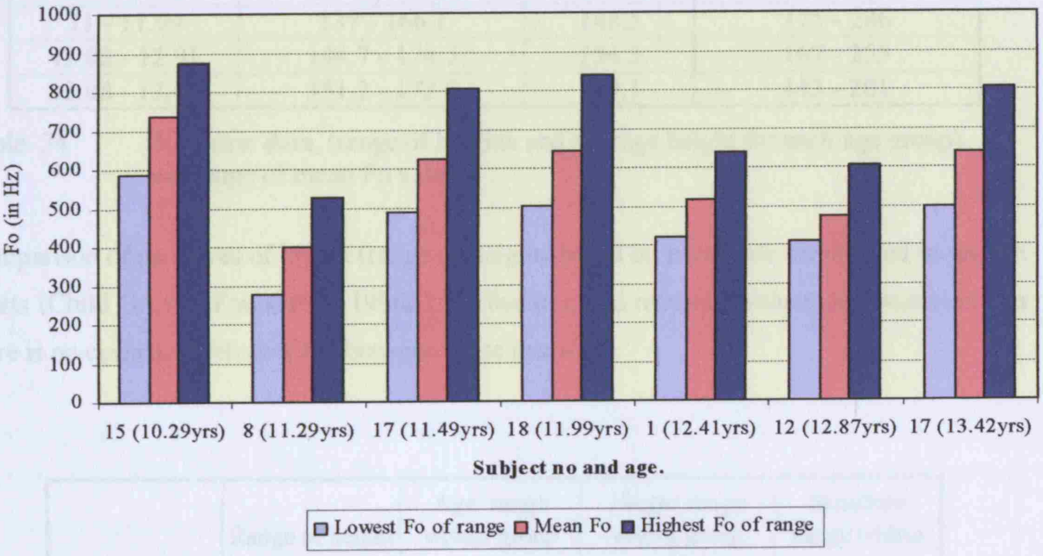


Fig 31 Fo data (lowest Fo of range, mean Fo and highest Fo of range) derived from singing in descant.

9.14 BIOMETRIC RESULTS

The relationship between changes in Fo associated with maturation, and between maturation and growth are clearly identifiable, (except where there are specific problems such as puberphonia and nanosomia)

9.14.1 <u>The relationship between certain biometric measures and mean Fo in speech</u>.

9.14.1.1 *HEIGHT*

The difference between the shortest and tallest subjects is 55.1cms, (range 119.4cms – 174.5cms).

Age range (in years)	Height range (in cms)	Average Height	Range of mean Fos (Hz)
8.01 - 8.98	119.4 - 139.5	129.3	214 - 348
9.12 - 9.97	125.2 - 151.1	137.3	194 - 273
10.01 - 10.97	126.8 - 161.8	143.5	180 - 273
11 - 11.99	137 - 166.1	148.5	175 - 286
12.02 - 12.91	144.7 - 174.5	154.3	167 - 253
13.08 - 13.42	151.2 - 172.8	159.1	143 - 201

Table 34 Biometric data, (range of heights and average height for each age group), and range of mean Fo values.

Comparison of measures of height (range of heights based on percentile bands used in growth charts (Child Growth Foundation 1996/ 1:5–18years), and mean Fo values demonstrated that there is no consistent relationship between these measures.

No. of samples	Range of height (in cms)	Age range within group (years)	Height range within group (cms)	Semitone range within group
3	119.4 - 123.1	0.31	3.7	1.9
4	126.3 - 129.7	1.37	3.4	3.7
8	130.8 - 134	2.3	3.2	5.1
10	135 - 139.1	2.95	4.1	4.4
11	140.1 - 143.7	2.61	3.6	7.7
16	144.7 - 148.5	3.36	3.8	9.3
16	149.3 - 153.6	3.9	4.3	7.1
7	154 - 157.5	2.69	3.5	4.1
7	159.8 - 164.5	2.87	4.7	6.9
2	172.8 - 174.5	1.28	1.7	4.8

Table 35 The range of ages, and difference in mean Fo values (in S/T) between

subjects matched by height (in 4 cm bands), and the number of samples in each group.

9.14.1.2 *SITTING HEIGHT*

Sitting height (which can be used to estimate thoracic length), was also measured. This measurement was typically between 51 – 55% of the total height, with the exception of five subjects.

Subject No.	17	23	28	32	32	24	33	33
Age (yrs)	13.42	10.4	11.22	11.48	9.39	9.45	8.32	9.3
Sitting height as % of total height	46	49	50	56	57	57	58	58

Table 36 Sitting height as a percentage of the total height for those subjects where this relationship differed from the typical ratio.

9.14.1.3 *WEIGHT*

The other measure used in the standard measures of growth is weight. The patterns of growth (weight and height) related to standard values are presented in appendix 8.

Age Range (in years)	Weight Range (in Kg)	Average Weight (Kg)
8.01 - 8.98	19.8 - 34.2	26.7
9.12 - 9.97	25.6 - 39.6	31.37
10.01 - 10.97	24.2 - 50	35.32
11 - 11.99	29.3 - 55.2	39.41
12.02 - 12.91	31.2 -62.4	43.29
13.08 - 13.42	34.8 - 56.5	44.06

Table 37 The range of weights and the average weight for each age group.

Grouping of subjects according to a range of weights based on percentile bands used in growth charts (Child Growth Foundation 1996/ 1:5–18years), identified very small differences in the youngest age groups (2kg), and a difference of 3.5Kg between the 50th and 25th percentile at age 11years. However, the fact that weight is affected by another variable (i.e. dietary factors and exercise) renders its usefulness as a measure of growth related to changes in mean Fo questionable.

9.14.1.4 *HEIGHT AND WEIGHT*

Comparison of results for subjects matched by age, and, based on the banding criteria referred to previously, by height and weight, failed to demonstrate any identifiable trends or relationships between the biometric measures and the mean Fo value (speech).

9.15 Vertical Laryngeal Dimension

Inspection of measurements considered reliable, demonstrates that the rate of growth of the larynx differs and is far more rapid than the overall rate of skeletal growth, as identified by measurement of full height. (The percentage increase is calculated from the increase between the first and third measurements.)

Subject No.	Age Range (in years)	Age interval (in years)	Increase in larynx size (in mm)	Percentage increase in larynx size	Increase in height (in cms)	Percentage increase in height	Lowering of mean Fo (in semitones)
28	10.01 - 12.03	2.0	4.4	20.0	12.3	8.8	0.7
22	10.24 - 12.27	2.0	5.4	29.0	9.1	6.5	2.4
21	10.29 - 12.29	2.0	3.3	18.8	11.0	7.6	1.7
16	11 - 12.89	1.9	3.5	14.3	9.0	6.2	6.5
12	10.83 - 12.87	2.0	3.4	17.3	10.4	6.9	3.9

Table 38 Laryngeal growth and lowering of the mean Fo (in S/T) in relation to age and height for 5 subjects.

These results indicate that, as would be expected, the relative changes are not proportionate. Fig 31 shows the growth for 8 subjects at 3 ages and demonstrates the variation in the rate of growth which is not related to age.

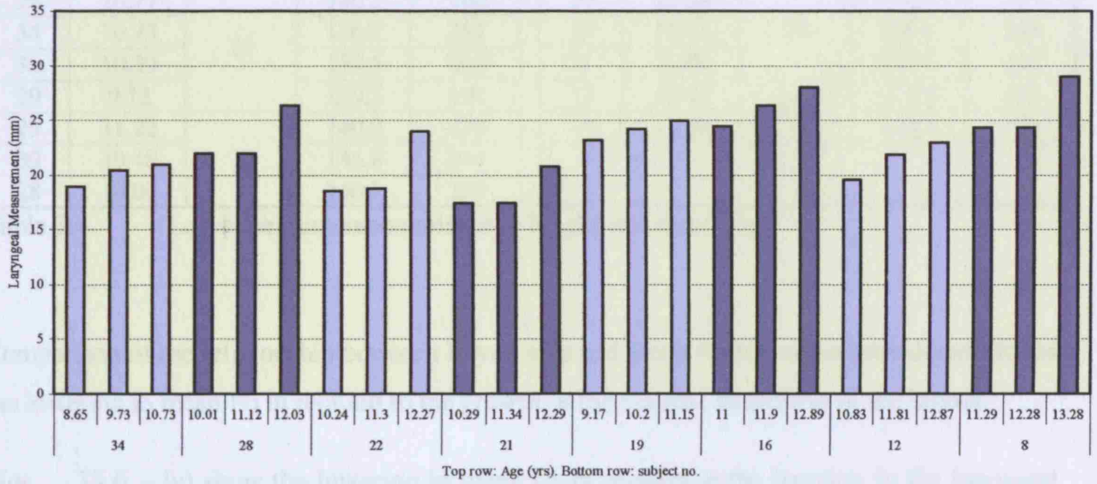


Fig 32 The laryngeal measurements for 8 subjects showing the differing rates of growth

- The increase in the laryngeal measurements for subjects 28, 22 and 21 suggests a growth spurt between age 11years and 12years.
- The rate of increase shown by subject 12 is more even across the age range.

➢ There is no identifiable change in the measurement for subject 8 between the ages of 11years and 12years, with a marked increase between the ages of 12years and 13years.

The data for the present study was reviewed with subjects whose external laryngeal dimensions were within 0.5mm grouped together. This showed age differences of between 2 and 4 years, and mean Fo differences (in S/T) of between 5 and 9.3 S/T.

Comparison of examples of measures of the laryngeal dimension and mean Fo values in subjects of the same overall height, demonstrates that there is no consistent or reliable relationship between these measures.

Subj no.	Age (in years)	Larynx (mm)	Height (cms)	Mean Fo (Hz)	Subj no.	Age (in years)	Larynx (mm)	Height (cms)	Mean Fo (Hz)
40	8.99	18.2	133.7	285	17	11.49	22.5	152.3	273
24	10.54		133.6	214	27	11.12		137.8	242
22	11.3	18.8	146	260	30	10.96		152.1	229
10	12.09		150.3	186	33	10.3		130.8	213
18	13.16	20	161.3	170	12	12.87	23	160.6	200
33	8.23		121.7	245	36	11.41		164.5	192
24	11.42	20.5	137	224	38	9.48		141	213
34	9.73		131.3	269	8	11.29	24.4	143.3	175
25	9.14		132	229	19	10.2		143.7	251
26	10.77	21	140.2	180	20	11.58	25	155.7	213
34	10.73		136.2	251	19	11.15		147.4	248
36	10.39		157.5	205	31	8.88		139.1	214
29	9.12		129.7	194	17	13.42	27.5	173.8	143
29	11.22	22	140.2	228	14	12.91		154.3	193
39	10.48		146.8	244					
28	10.01		140.1	239					

Table 39 Laryngeal dimension related to height and mean Fo

Comparison of the relationship between larynx size and mean Fo for individuals demonstrates the lowering in mean Fo in relation to the growth in the vertical dimension of the larynx.

Figs 33 (i – iv) show the lowering in mean Fo in relation to the increase in the laryngeal dimension as a function of age for subjects 28.17, 12 and 16

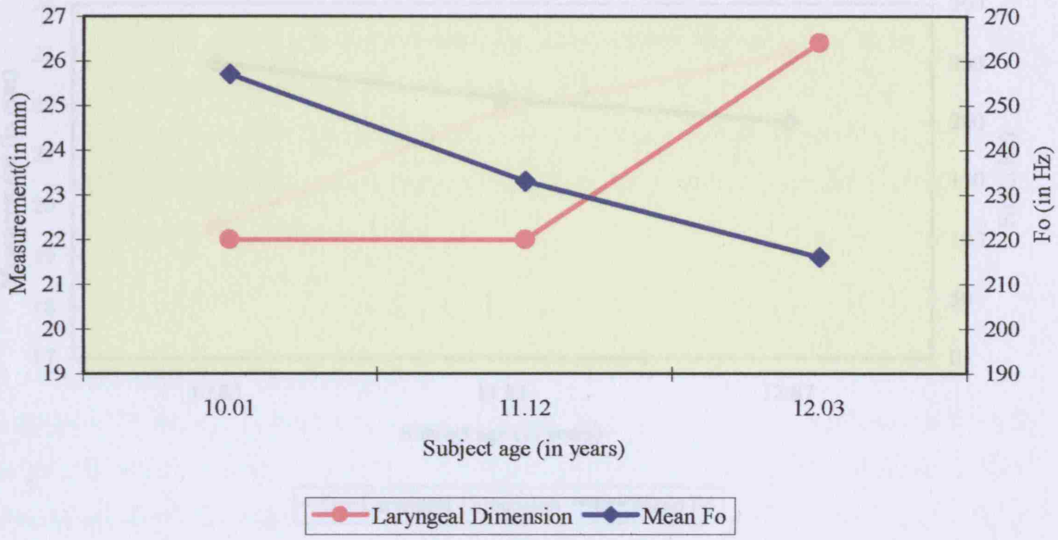


Fig 33(i) Subject 28

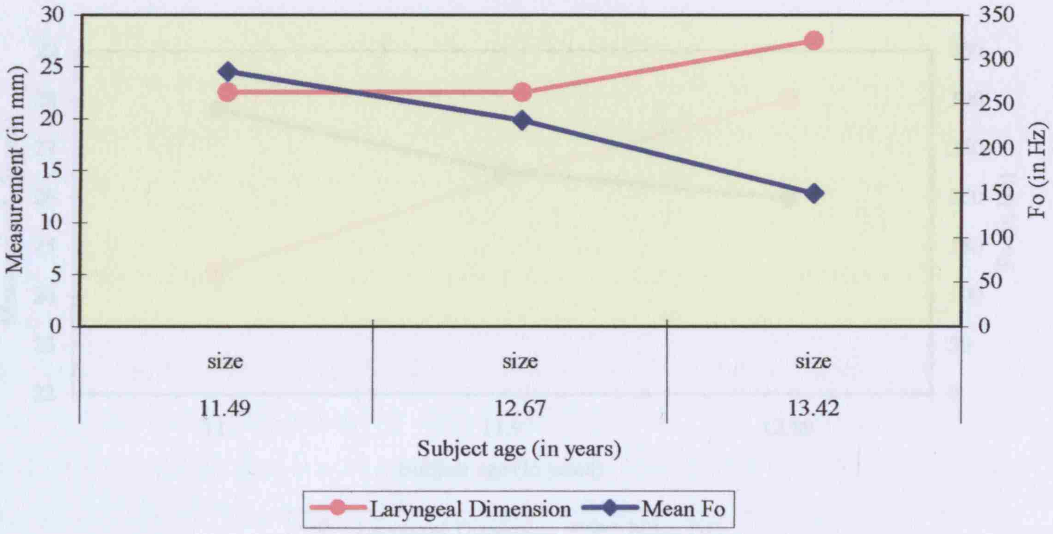


Fig 33 (ii) Subject 17

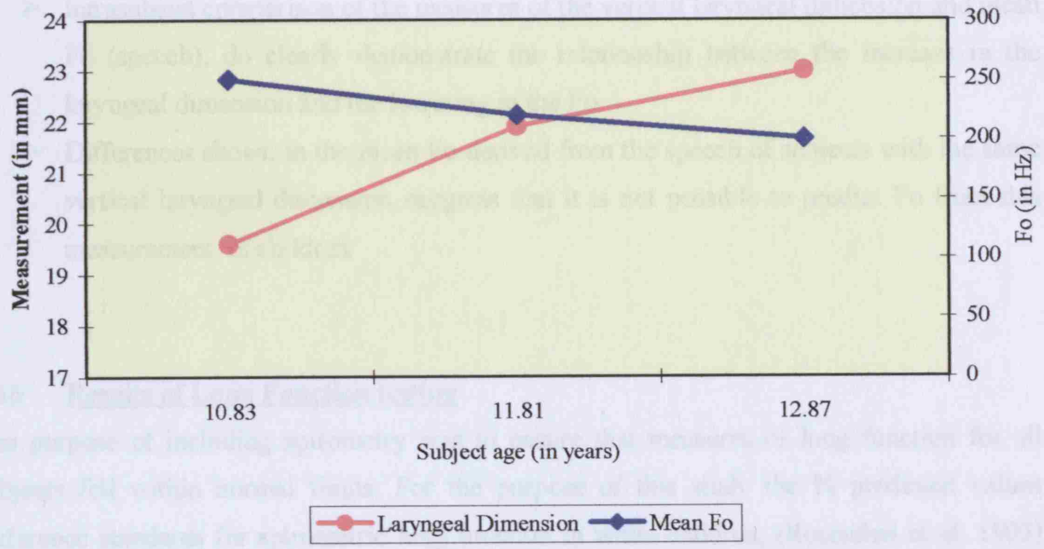


Fig 33 (iii) Subject 12

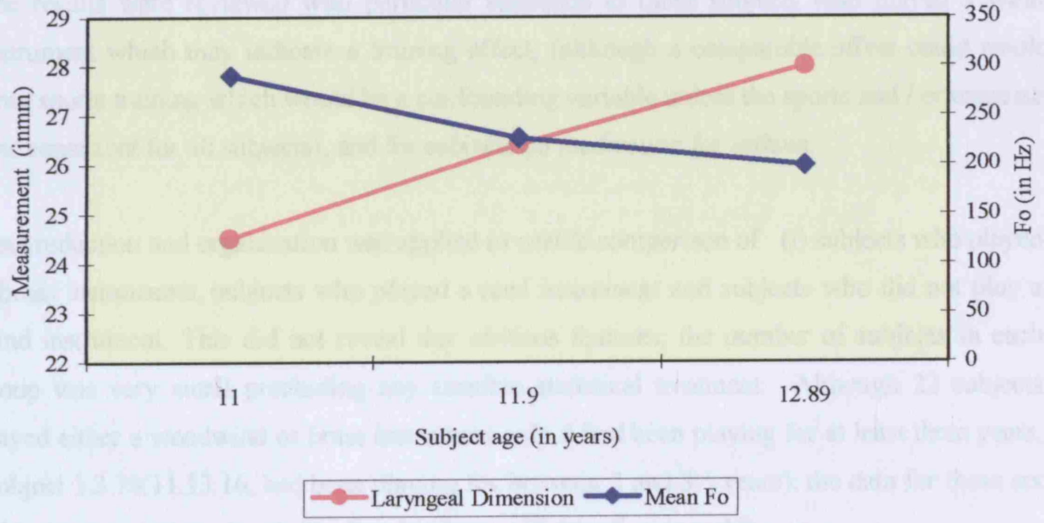


Fig 33 (iv) Subject 16

Although the results are limited by (a) the relatively small number of subjects, and (b) the time between the data collections; this latter being particularly pertinent for children at a period of rapid growth, these findings indicate that:-

- Comparison of the biometric measures of height, weight and vertical dimension do not demonstrate any obvious inter subject trends relating to Fo.

- Intrasubject comparison of the measures of the vertical laryngeal dimension and mean Fo (speech), do clearly demonstrate the relationship between the increase in the laryngeal dimension and the lowering in the Fo.
- Differences shown in the mean Fo derived from the speech of subjects with the same vertical laryngeal dimension suggests that it is not possible to predict Fo from this measurement in children.

9.16 Results of Lung Function testing

The purpose of including spirometry was to ensure that measures of lung function for all subjects fell within normal limits. For the purpose of this study the % predicted values (reference standards for spirometric lung function in white children, (Rosenthal et al. 1993) were reviewed. The results for all subjects were considered normal, (80 – 120% of predicted values).(Appendix 9).

The results were reviewed with particular reference to those subjects who played a wind instrument which may indicate a training effect, (although a comparable effect could result from sports training which would be a confounding variable unless the sports and / or exercise was consistent for all subjects), and for subjects on medication for asthma.

Data reduction and organization was applied to enable comparison of (i) subjects who played a brass instruments, subjects who played a reed instrument and subjects who did not play a wind instrument. This did not reveal any obvious features; the number of subjects in each group was very small precluding any sensible statistical treatment. Although 22 subjects played either a woodwind or brass instrument only 6 had been playing for at least three years, (subject 1.3.10.11.13.16, had been playing for between 3 and 3½ years); the data for these six subjects was compared with the data for three subjects of comparable age.

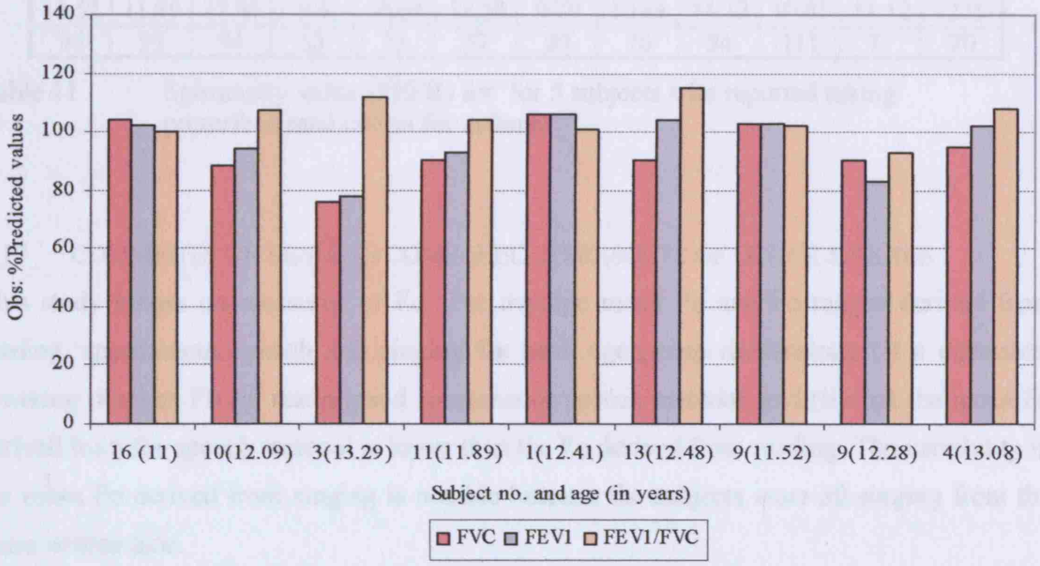


Fig 34. Spirometry values (FVC. FEV1. and FEV1/FVC for 3 subjects who play a wind instrument, (nos. 16.10.3); 3 subjects who play a brass instrument, (nos. 11.1.13), and 3 subjects who do not play any wind instrument, (nos. 9.8.4).

16	10	3	11	1	13	9	8	4
11	12.09	13.29	11.89	12.41	12.48	11.52	12.28	13.08
Clarinet	Flute	Oboe	Trombone	Trumpet	French Horn	No wind instument played		

Table 40. Spirometry value (PEFR) for 6 subjects who play a woodwind or brass instrument and 3 subjects who do not play any wind instrument.

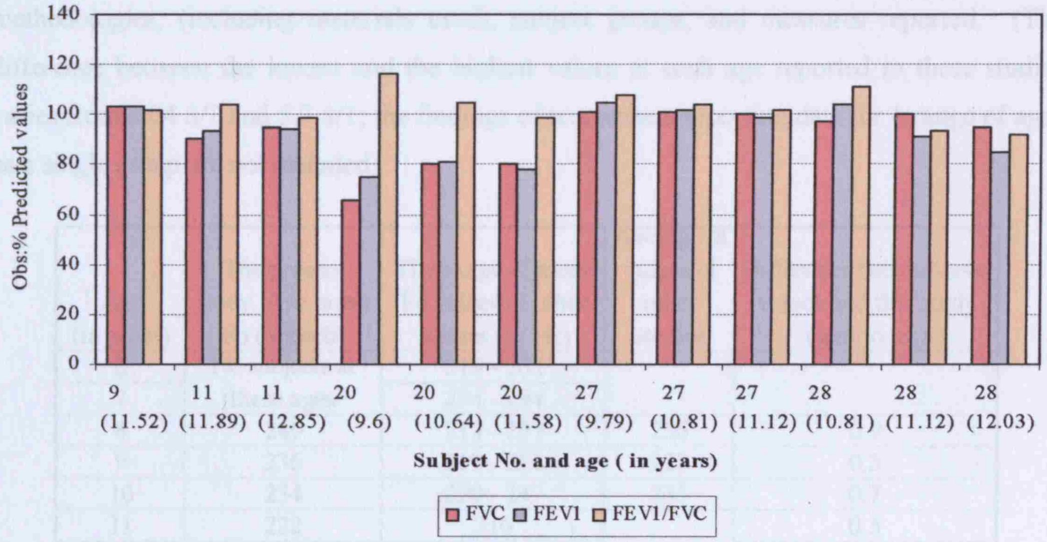


Fig 35. Spirometry values (FVC. FEV1. and FEV1/FVC for 5 subjects who reported taking prescribed medication for asthma.

9	11		20			27			28		
11.52	11.89	12.85	9.6	10.64	11.58	9.79	10.81	11.12	10.81	11.12	12.03
95	95	94	63	73	57	89	76	94	111	77	70

Table 41 Spirometry value (PEFR) for for 5 subjects who reported taking prescribed medication for asthma.

9.17 COMMENTS ON RESULTS COMPARED TO RESULTS OF OTHER STUDIES

This study hinges on measures of Fo. The average mean Fo and Fo ranges derived from reading, spontaneous speech and singing for each age group demonstrate (i) a consistent lowering of mean Fo for reading and spontaneous speech material, and (ii) that the mean Fo derived from the speech material is lower than the Fo derived from reading. The variability in the mean Fo derived from singing is notable because the subjects were all singing from the same written tune.

9.17.1 *SPONTANEOUS SPEECH*

The relationship between maturation and lowering of the mean Fo is evident in the findings of this study which demonstrate a lowering of the mean speaking Fo by 6.3 S/T between the ages of 8.01years and 13.42years,.

These results are comparable to those reported in other studies of male adolescent voice referred to; however the relevance of cross-referencing is limited because of the diversity of methodologies, (including materials used), subject groups, and measures reported. (The difference between the lowest and the highest values at each age reported in these studies varies from 2.04 S/T and 5.7 S/T; the findings of researchers reporting data for a range of ages as a single group are not included).

Age (in years)	The present study. Ave mean Fo (Speech)	The range of mean Fo values of other studies (in Hz)	Average of values of other studies	Difference between ave. values and this study (semitones)
6	No subjects at these ages	219 - 262		
7		234 - 294		
8	249	213 - 297	236	0.9
9	236	219 - 262	227	0.5
10	234	220 - 247	231	0.7
11	222	216		0.5
12	207	233		2.1
13	175	174		0.2

Table 42 The average mean Fo (speech) compared to values reported in other studies.

Comparison of the average mean Fo values with those reported by other researchers, show that the differences (in S/T) are small, with the exception of the 12-year-old subjects, (the average value 2.1 S/T lower than that reported by Hollien et al for American boys (1994). The average value for the age groups 8-12 years, and 8–13 years, (i.e. the closest to the age groups used by Pedersen (Danish subjects), and by Barlow and Howard (British subjects)), are comparable to the average of the other studies reported, and differ from those reported by Pedersen and by Barlow and Howard.

The average value for the group age 8–13 years differs from the Pedersen values by 3.6 S/T, and from the Barlow and Howard values by 2.0 S/T; these values drop to 2.9 S/T and 1.3 S/T respectively if the group average is derived from the values for subjects age 8-12 years.

Notably the values are comparable to those found in another UK study of children's voice reporting Fo data, (Whiteside et al. 2000).

Age (in years)	Present Study	Whiteside et al (2000)	Difference in values Hz	Semitones
8	249	255.4	6.4	0.4
10	234	224	9.5	0.8

Table 43 Fo values from the present study compared to values reported for another UK study.

The difference between the average values of adjacent age groups in S/T shows an uneven trend, with the lowering in Fo from twelve years to thirteen years more than twice that of the previous age group. (2.8 S/T compared to 1.3 S/T).

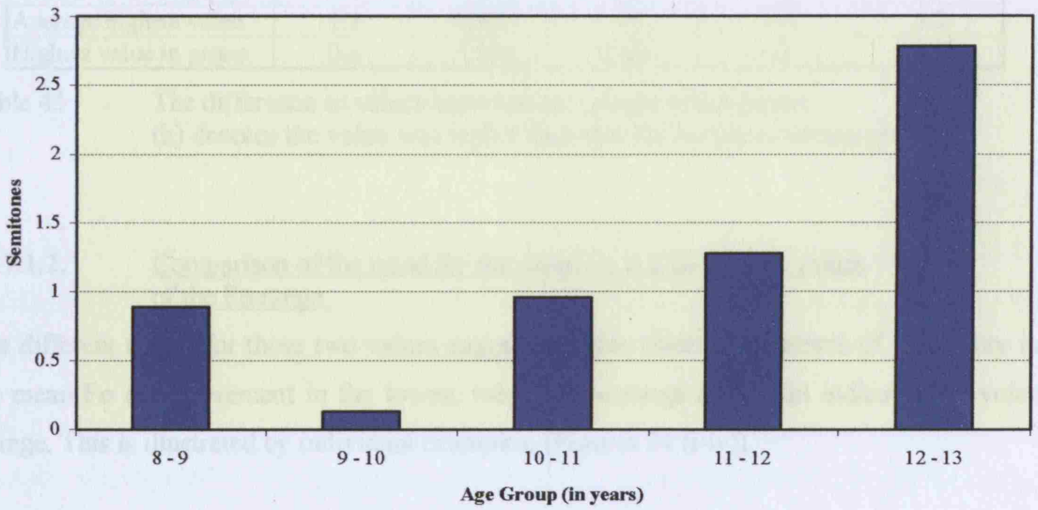


Fig 36 The average lowering of mean Fo (in S/T) between age groups.

In the current study values for speech Fo below 195Hz were found for 15 subjects, and above 195Hz but below 249Hz for 28 subjects). The age distribution is shown below.

Age (in years)	8	9	10	11	12	13
Mean Fo below 195Hz	0	1	2	4	7	4
Mean Fo above 195Hz and below 249Hz	4	7	10	11	9	0

Table 44 The distribution of samples in each age group related to mean Fo criteria used in other studies.

41% of all the subjects showed a consistent decrease in the mean Fo, with the remainder showing one or more values higher than the preceding value. This occurs mainly in the younger age groups, diminishing with the age increases and suggests that monitoring of the variation in Fo over shorter time intervals would demonstrate the instability of pitch associated with maturation, (as described by Hollien et al (1994).

9.17.1.1. Fo range (Speech)

Table 45 shows the difference in the mean Fo and range values between age groups in S/T. The average lowest and highest values of the frequency range for each age group is summarised for all materials at the end of this section. (Table 53)

	Age group (in years)				
	8 - 9	9 - 10	10 - 11	11 - 12	12 - 13
Average mean Fo	0.9	0.1	1.0	1.3	2.8
Average lowest value	0.7	0.8	0.6	1.1	4.0
Lowest value in group	3.0	0.2(h)	1.7	1.2	3.9
Average highest value	1.3	0.8(h)	0.3	2.4	3.2
Highest value in group	0.8	3.9(h)	0.4(h)	6.4	4.5

Table 45 The difference in values between age groups in semitones.
(h) denotes the value was higher than that for the previous age group.

9.17.1.2. Comparison of the trend for the mean Fo and the lowest values of the Fo range.

The different trends for these two values suggest that the combined features of variability in the mean Fo and movement in the lowest value of the range are useful indicators of voice change. This is illustrated by individual examples, (Figures 34 (i-iv)).

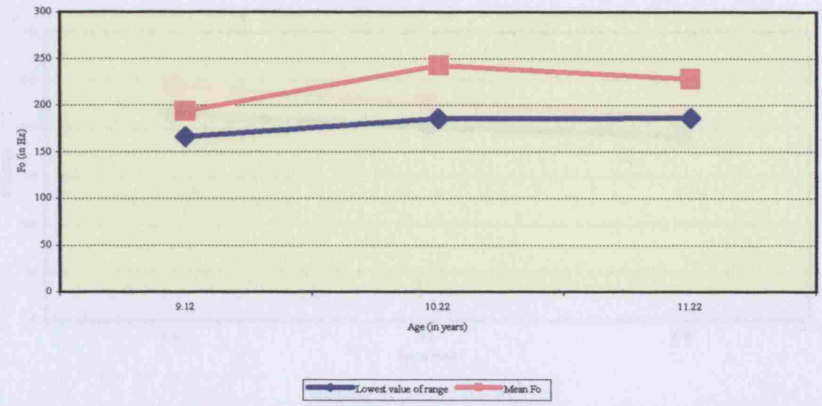


Fig 37(i) The relationship between the mean Fo and the lowest value of the Fo range at ages 9, 10 and 11 years for subject 29.

<u>Subject 29</u> The lowest value of the range and the mean Fo are higher at age 10.22years than at age 9.12years; the mean Fo then drops by 1.04 S/T at age 11.22years but the lowest value of the range is practically the same.

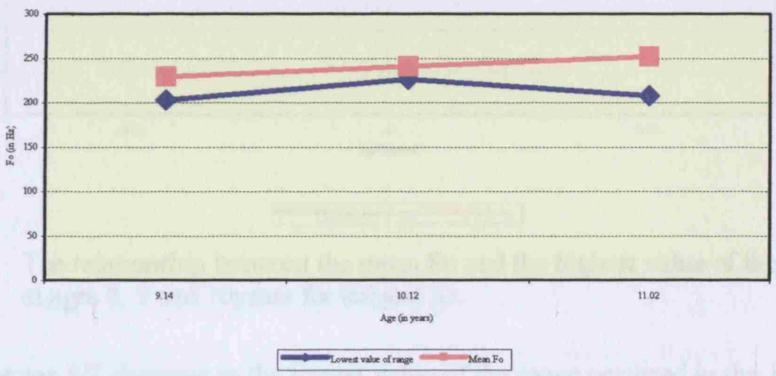


Fig 37(ii) The relationship between the mean Fo and the lowest value of the Fo range at ages 9, 10 and 11 years for subject 25.

<u>Subject 25</u> Both values higher at age 10.12years compared to age 9.1years; the mean Fo is slightly higher at age 11.02years compared to age 10.12years (0.7 S/T), but the lowest value of the range has dropped by 1.5 S/T between age 10.12years and age 11.02years

This is contrasted with the relative stability found in younger subjects as shown by the example of comparative consistency between the mean Fo and the lowest value of the range, and between the mean Fo and the highest value of the range, (1.1 S/T at age 9.3 years, and 1.3 S/T at age 10.3 years).

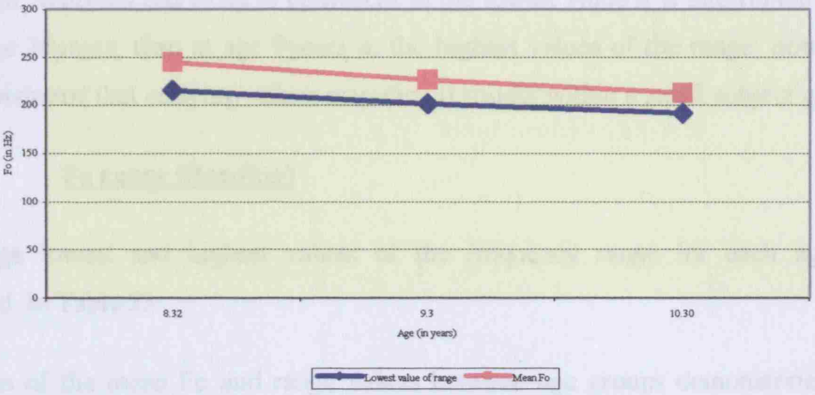


Fig 37 (iii) The relationship between the mean Fo and the lowest value of the Fo range at ages 8, 9 and 10years for subject 33.

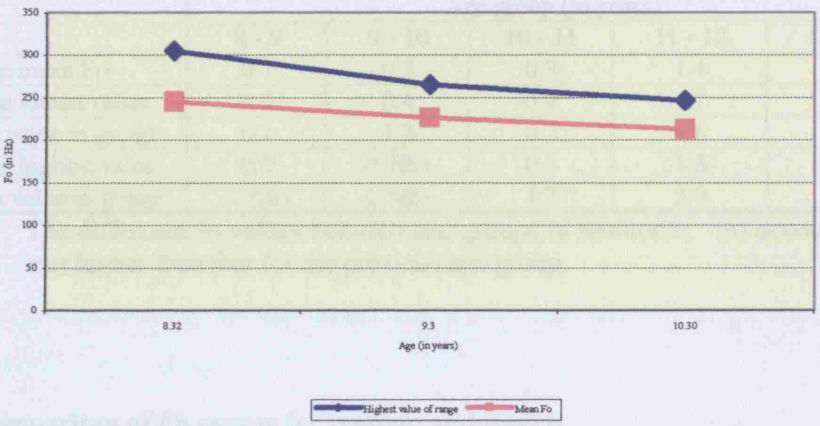


Fig 37 (iv) The relationship between the mean Fo and the highest value of the Fo range at ages 8, 9 and 10years for subject 33.

The largest average S/T decrease in the lowest value of the range occurred in the 10 – 11year-old group:-

Age (in years)	8 - 9	9 - 10	10 - 11	11 - 12	12 - 13
Semitones	1.1	0.6	1.7	1.3	1.2

Table 46 The average decrease in the lowest value of the Fo range for each age group.

9.17.2 *READING*

The results of the present study differ from values reported for reading by Sorensen ((1989) 0.2 semitone, 10-year-old subjects), and Morris ((1997) 2.9 S/T, 8-year-old subjects)).

The results of this study demonstrate the downward trend in the lowest and highest values of the Fo range. Whereas this trend is consistent in the lowest value it is interrupted by a higher value at age 10years, than at age 9years in the highest values of the range; however, it has been demonstrated that outlying values may distort results within a small subject group.

9.17.2.1 Fo range (Reading)

The average lowest and highest values of the frequency range for each age group is summarised in Table 53.

Comparison of the mean Fo and range values between age groups demonstrates the larger interval in the highest value of the range between the ages of 12years and 13years compared to both the mean and the lowest value intervals.

	Age group (in years)				
	8 - 9	9 - 10	10 - 11	11 - 12	12 - 13
Average mean Fo	0.7	0.3	0.3	1.4	2.8
Average lowest value	0.6	0.4	0.9	1.7	1.6
Lowest value in group	0.1	1.2	0.7	1.6	1.9
Average highest value	0.2	0.7(h)	0.1	1.6	3.8
Highest value in group	2.7(h)	2.5(h)	1.7	3.0	4.5

Table 47 The difference in values between age groups in semitones. (h) denotes the value was higher than that for the previous age group

9.17.3 Comparison of Fo ranges for reading and speech

The average Fo range is used as the reference for comparison with the narrowest range and the widest range identified in each age group and demonstrates the extent of variation.

Age group	Reading			Speech		
(in years)	Narrowest	Widest	Average	Narrowest	Widest	Average
8	3.7	7.8	5.7	3.4	11.0	5.8
9	3.9	8.2	6.0	3.7	7.7	5.4
10	4.0	11.5	7.8	3.6	11.3	6.4
11	4.0	12.0	7.8	2.9	15.0	7.0
12	5.5	13.0	7.9	3.1	7.8	6.0
13	1.7	8.9	6.2	4.0	8.5	6.9

Table 48 The average, narrowest and widest Fo ranges derived from spontaneous speech and reading for each age group, (in S/T).

9.18 Summary of results derived from singing.

The lowering in the average mean Fo values does not follow a consistent trend. Despite the fact that the subjects were all meant to be singing the same tune, in the same key there is a difference of 5.4 S/T between the mean Fo at age 8years and age 13years.

	Age group (in years)				
	8 - 9	9 - 10	10 - 11	11 - 12	12 - 13
Average mean Fo	1.1	1.3 (h)	1.6(h)	0.9	6.3
Average lowest value	0.4	1.2(h)	0.7 (h)	*	7.5
Lowest value in group	0.6	1.0 (h)	0.1(h)	2.7	3.9
Average highest value	0.8	1.9 (h)	1.0(h)	1.3	6.2
Highest value in group	0.8	2.7 (h)	4.1(h)	3.7	8.7

(* value comparable to age 10-11yrs)

Table 49 The difference in values between age groups in S/T. (h) denotes the value was higher than that for the previous age group

Notably all the values are higher at age 10years, than age 9years, and higher at age 11years than at age 10years. The difference between the lowest values used at ages 12years and 11years is negligible (0.3Hz), whereas the highest value falls by 3.6 S/T. The fall in all values from age 12years to 13years is substantial, although this finding is viewed in the context of the small subject group at age 13years.

The average Fo ranges are within one S/T difference; however there is a broad spectrum of ranges within each age group. Notably the age group with the average value for the range closest to that of the music score (13 S/T) is the 12-year-group. Whereas the S/T value for the group average fell short of that range in the 8, 9, 10 and 13-year-old groups the average for the 11-year-old subjects exceeded it; which may reflect instability around at this age occurring in the age group which would be expected to be showing any effect of training.

	Age (in years)					
Fo Range	8	9	10	11	12	13
Average	9.2	9	9.4	9.6	9.8	9.8
Narrowest	5.8	6.14	5.6	5.99	6.3	8.3
Widest	11.2	11.4	11.9	15	12.7	11.2

Table 50 The average, narrowest and widest Fo ranges for each age group in S/T.

9.19 Comparison of results from spontaneous speech, reading and singing.

The largest difference between the average mean Fo derived from reading to that derived from speech is found in the 11-year-old group; the differences at ages 11years, 12years and 13years are slightly larger than those found in the younger age groups:-

Age in years:	8	9	10	11	12	13
Semitones:	0.8	0.9	0.7	1.4	1.3	1.3

Comparison between the mean Fo values derived from singing with the Fo derived from both reading and speech is not relevant because the mean Fo for singing is governed by the tune. However, it is noted that the mean Fo for singing for subjects age 13years is 5.4 S/T lower than that of the 8-year-old group; it does not follow a consistent downward trend and the largest difference is found in the 11-13-year-old groups.

Taking account of the relatively small sample size inspection of the extent of mean Fo values within each age group shows substantial differences between the lowest mean Fo and the highest mean Fo in each age group; this range of mean Fo values is particularly remarkable in the data derived from singing in the context of a set tune and pitch range.

Age Group	Material		
(years)	Reading	Speech	Singing
8	5.1	4.2	7.7
9	7.7	6.7	8.0
10	7.0	7.2	12.2
11	8.0	8.5	10.0
12	7.8	7.2	15.7
13	6.2	4.1	9.2

Table 51 The difference between the lowest mean Fo and the highest mean Fo derived from reading, speech and singing, in S/T, for each age group.

9.19.1. Comparison of Fo range values.

Comparison of the average of the lowest values of the range, and the highest values of the range for each age group (in S/T) shows the greatest variability in the lowest values in reading and the highest values in speech in the age groups 11-13years.

Material	Ave. Fo value	Age (in years)				
		8 - 9	9 - 10	10 - 11	11 - 12	12 - 13
Reading	Lowest	0.6	0.4	0.9	1.7	1.6
	Highest	0.2	0.7(h)	0.1	1.6	3.8
Speech	Lowest	0.7	0.8	0.6	1.1	4.0
	Highest	1.3	0.8(h)	0.3	2.4	3.2

Table 52 The difference in S/T between the average lowest and highest values of the Fo range derived from reading and speech for each age group; (h) denotes a higher value than the previous year.

The highest value of the range for one subject in the 11-year-old group was much higher (754Hz); this is not included in the group as it resulted from erratic outlying values and inclusion would distort the group result. The results derived from reading and speech show a consistent downward trend; this is not demonstrated in the results derived from singing which show a fall at 9-years, followed by a rise at age 10years, a further rise at 11 years before falling again at ages 12 and 13-years.

The lowest and highest Fo in each group is shown for reading speech and singing and the difference in S/T, is shown with the average highest and lowest value for each age group.

Age group (in years)	Fo Range	Material					
		Reading		Speech		Singing	
8	Lowest	180	260	196	251	214	326
	Average	225		219		266	
	S/T diff	6		4		7	
	Highest	259	348	247	385	339	576
	Average	313		311		457	
	S/T diff	6		8		9	
9	Lowest	181	277	165	255	207	348
	Average	217		210		260	
	S/T diff	7		8		9	
	Highest	260	407	233	367	356	551
	Average	309		288		437	
	S/T diff	8		8		8	
10	Lowest	169	281	167	233	215	391
	Average	212		201		279	
	S/T diff	9		6		10	
	Highest	241	471	207	460	339	644
	Average	322		302		487	
	S/T diff	12		14		11	
11	Lowest	162	247	152	221	217	427
	Average	201		194		291	
	S/T diff	7		6		12	
	Highest	221	427	201	472	342	816
	Average	319		297		517	
	S/T diff	13		15		15	
12	Lowest	148	220	142	217	185	438
	Average	182		182..23		291	
	S/T diff	7		9		15	
	Highest	210	357	202	325	270	659
	Average	291		259		480	
	S/T diff	9		8		15	
13	Lowest	132	220	113	159	148	231
	Average	167		144		188	
	S/T diff	9		6		8	
	Highest	183	276	185	250	238	398
	Average	233		216		335	
	S/T diff	7		5		9	

Table 53 Summary of the lowest and highest Fo values derived from reading, speech and singing for each age group, showing the difference between them in S/T, and the average lowest and highest value of the range, for each age group.

From this data it is evident that group values conceal the extent of variation between subjects of the same age, and do not adequately reflect the process of change between age groups.

9.20 Summary of results related to biometric measures.

9.20.1 MEASURES OF HEIGHT AND WEIGHT

Measures of height and weight did not reveal any remarkable features in most of the subjects. One subject was very tall for his age with indications of precocious maturation; and two subjects were very small for their age, (one at the age of 10½ years was the height of the average 9½-year-old).

Biometric Measure	Below ave	Average	Above Ave
Weight	30%	35%	35%
Height	25%	40%	35%
Height/weight matched	7%	20%	12.50%
Underweight for Height	7.5% (one subject very underweight)		

Table 54 Summary of results of measures of height and weight (based on UK cross-sectional reference data (Child Growth Foundation 1996/1 updated 2002).

Differences from average within age groups varied from 20.1cms– 35cms in height, and from 14.09Kg- 31.2Kg in weight. Both height and weight measures increased appropriately in relation to chronological age. The number of subjects of exactly the same age was too small to test the hypothesis that height and Fo are inversely related; although this was noted in comparison of two subjects at each age, 10.29years, 10.48years and 11.15years.

Combinations of measures were inspected to identify any consistent relationships:-

- Subjects of similar height (within 0.5cm) with comparable mean Fo values (within 10Hz)
- Subjects of similar height (within 0.5cm) with a difference in mean Fo values greater than 20Hz.
- Subjects of similar height ((a) within 1 cm; (b) within 4cms)
- Subjects matched by weight
- Subjects matched by height and weight

The results supported the obvious relationship between increasing height and weight and chronological age but did not demonstrate any relationship between biometric measures and Fo independently. Evidence of an intrasubject relationship between an increase in the vertical laryngeal dimension and lowering of the mean Fo is consistent with this finding.

CHAPTER X RESULTS AND DISCUSSION OF VOICE QUALITY

10 Temporal Irregularity

For the purpose of the present study, with no evidence of any clinical problems or reported abnormal auditory features in the voices of the subjects, the ELG analyses are examined to detect any trends or features of the DFx distribution histograms, (symmetry, the range, the number of peaks and congruence of DFx1 and DFx2) and the CFx crossplot,(range, density and scatter), related to maturation.

10.1 Classification of DFx Histograms

Based on visual examination a classification system was designed, intended to identify degrees of stylisation (previously referred to), yet be reasonably concise.

10.1.1 Features of DFx1 and DFx2

SYMMETRY gives an indication of the probability of the use of the high/low Fo. The distributions are sub-divided into narrow range (N) and wide range (W), where these features are remarkable. Symmetry is determined by the use of the frequencies which is influenced by many factors including task, articulatory behaviour and mood, therefore an asymmetrical distribution is neither unusual nor abnormal; symmetry is not expected in normal speakers, although adult male speakers are inclined to have more symmetrical distributions than young women.

ASYMMETRY indicates the bias of the pitch range in relation to the modal frequency. The direction of the excess tail to the distribution indicates the direction of skewness. The probability of high/ low frequencies may be biased so the distribution will be asymmetrical with a bias to the low frequencies (AL) or to the high frequencies (AH).

MULTIMODAL. Regularity in vocal fold vibration is reflected in a single distribution with one dominant modal value, although there will be other modal peaks. High probability of another range of values generates secondary modes. These secondary modes may be either high frequency (MH) or low frequency (ML).

PEAKING. This indicates where additional peaks occurred, either high (EH) or low (EL) (The degree to which the main frequency distribution curve is peaked or flattened is referred to as kurtosis).

Using this framework the distributions were rated against 11 criteria. However when applied to the histograms it became apparent that the categories (AH/AL) failed to distinguish between distributions which were slightly asymmetrical and those where the asymmetry is more obvious.

'A' was used for distributions which appeared symmetrical but show slight differences in probability. Categories AH /AL were only used for histograms which were markedly asymmetrical.

The use of 'narrow' and 'wide' did not accommodate those distributions which did not obviously fall into either category.

Combining symmetry and width resulted in an unnecessary duplication which confused rather than clarified the over-view.

Symmetry	Width	Multimodal	Peaks
Symmetical (S)	Average (Ave)	Low (ML)	Extra High peaks (EH)
Asymmetrical (A)	Narrow (N)	High (MH)	Extra Low peaks (EL)
Asymmetrical (Low)	Wide (N)		
Asymmetrical High (AH)			

Table 54 Revised classification of DFx distribution histograms

10.2 Classification of CFx crossplots

The features of the CFx crossplots which are most relevant are the length, correlating to the frequency range; how compact/dense the plot is and the amount and form of the scatter in relation to the core diagonal.

The first two features were categorised as wide (W), average (Ave) or narrow (N).Where the voice is regular this diagonal is clearly defined, compared to a more diffuse diagonal reflecting irregularity. The scatter is frequency related and as such could be classified as low (L), mid-range (MS) or high (H); this did not accommodate those CFx crossplots which have diffuse spread of scatter so the additional category was used to describe this (D). A further feature which may appear is discontinuity where there is a gap in the frequencies used which is shown by a broken CFx diagonal relating to multimodal DFx histograms. (B)

A review of the crossplots identified the feature of scatter parallel to the diagonal, This is noted by (P). (Appendix 10)

These classifications failed to adequately reflect some notable features:-

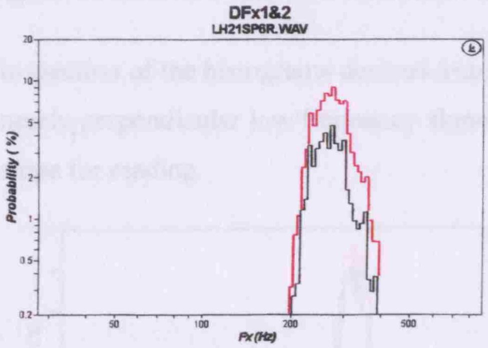
- The extent of DFx asymmetry. Although the feature of symmetry is not necessarily relevant the pattern of asymmetry may be interesting for intra-subject comparisons.
- The steepness and tiering of the DFx histogram This is particularly relevant reflecting the probability of frequencies, and may indicate subtle changes in the

use of frequencies which are not significant enough to be reflected in mean, mode and median Fo.

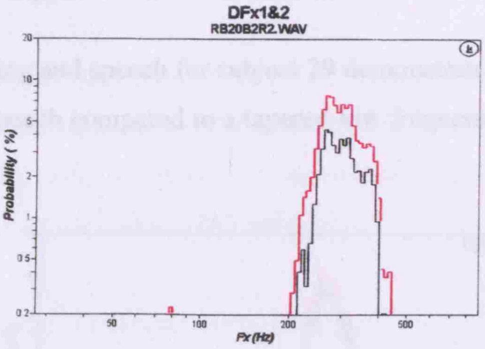
- The descriptions of the CFx crossplots did not adequately distinguish a long plot with an even distribution of values from one with a wide range but small range of concentration of values.

These features are illustrated in the following examples of histograms:-.

Examples of DFx Histograms



Subject 20



Subject 21

Diagram 15. Examples of asymmetrical histograms. The red line represents DFx1; the black line shows DFx 2.

The difference between DFx1 and DFx2 values is:- mean 1.8 S/Ts; DFx1 median values 1.29 S/T; DFx2 median values 1.7 S/T. The subjects are a similar age, (subject 21, 10.29yrs; subject 20, 10.64yrs).

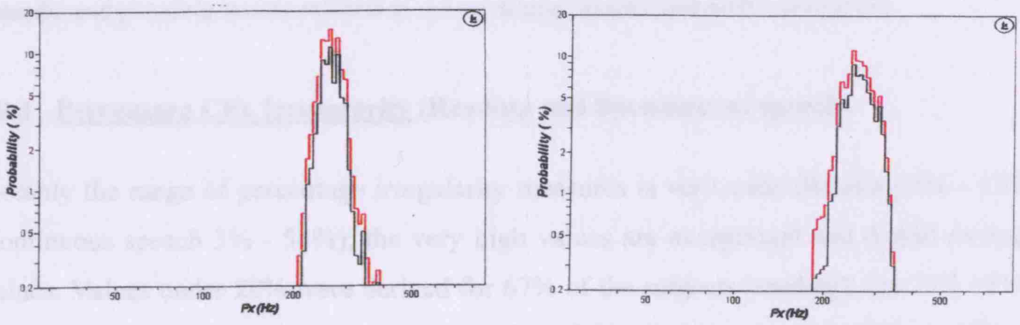
The percentage irregularity is slightly higher for subject 21 (11% compared to 8%), whereas subject 21 demonstrates close congruence between DFx1 and DFx2 in the lower frequencies, with a more conspicuous discrepancy in probability in the higher frequencies. The difference between the lowest value in the DFx1 range for these two subjects is 0.2 S/T, compared to 1.4 S/T from DFx2, (values DFx1: 217Hz and 214Hz; DFx2: 242Hz and 222Hz). The difference between the lowest DFx1 and DFx2 values, is 0.6 S/T for subject 21, compared to 1.8 S/T for subject 20. This may be indicative of more stability in the lower frequencies, whereas subject 20 is showing more stability in the upper frequencies. Therefore, although both histograms can be categorised as asymmetrical, the configurations are markedly different.

Subject 20: The high frequency slope is more nearly perpendicular compared to the well defined tiers for subject 21. The low frequency slope is less acute in subject 21 (a difference of approximately 10°, the low frequency slope for subject appears perpendicular but is at an angle of approximately 80°).

Symmetry in the DFx2 histogram was noted in the older subjects more than the younger subjects; however the relatively small number of subjects and the variability preclude generalisation of this observation.

The structure of the low frequency slope, (ie the pattern resulting from the differing probabilities of the frequencies), was noted to differ in the youngest subjects; however, again the number of samples is not sufficient to support a robust conclusion.

Inspection of the histograms derived from reading and speech for subject 29 demonstrate a nearly perpendicular low frequency slope for speech compared to a tapered low frequency slope for reading.

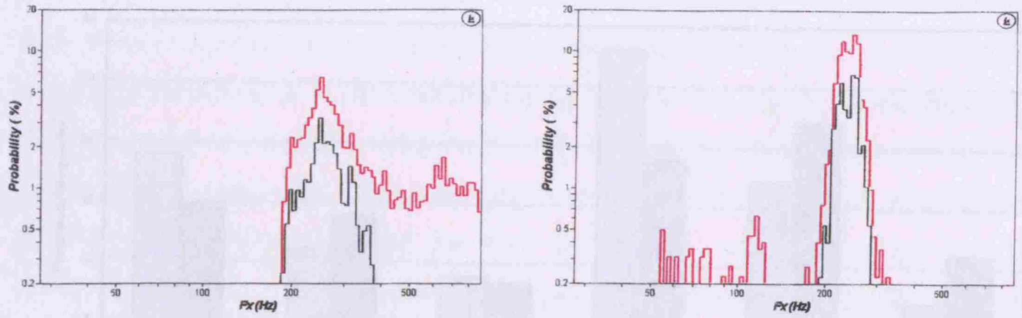


(i) (ii)

Diagram 16. Histograms derived from reading (i) and speech (ii). (subject 29).

The difference between the mean Fo values,(reading and speech), and between the lowest value of the ranges (reading and speech) are the same, (1.5 S/T); the values from reading are higher than those from speech. This finding is not unexpected but demonstrates the relevance of choice of material to interpretation of the histogram configuration.

Examples of high frequency irregularity, and low frequency irregularity in the DFx1 histograms which is eliminated in the DFx2 histograms are shown for subjects 18 (high frequency) and 2 (low frequency) for distributions derived from speech. .



(i) (ii)

Diagram.17. Histograms derived from speech, (subject 18).

These results indicate that more information can be deduced from the shape of the distribution histogram and that detailed descriptions and statistical analyses of measures of skew and kurtosis will be useful to identify the characteristics of voice use for a given sample and possible trends related to voice change associated with maturation.

10.3 Percentage CFx Irregularity (Reading and Spontaneous speech)

Notably the range of percentage irregularity measures is very wide (Reading 2% - 52%; Continuous speech 3% - 54%); the very high values are exceptional and distort average values. Values under 20% were derived for 67% of the subjects (reading), for 75% of the subjects (speech). In reading the values for 79% of this group were under 10%, (ie.53% of the whole group), and in speech 56% had values under 10%, (ie 42% of the whole group). Percentage irregularity of less than 5% was found in 27% of the subjects for reading, compared to 14% in speech, and 11% in both reading and speech.

The group averages for reading and speech are close, (reading 11%; speech 12%); however, in view of the age range (8.01yrs – 13.29yrs), and the changes which could be expected to occur over that time in terms of growth and development, educational and social influences it is questionable whether a group average measure is at all relevant; especially when derived from such a small number of subjects.

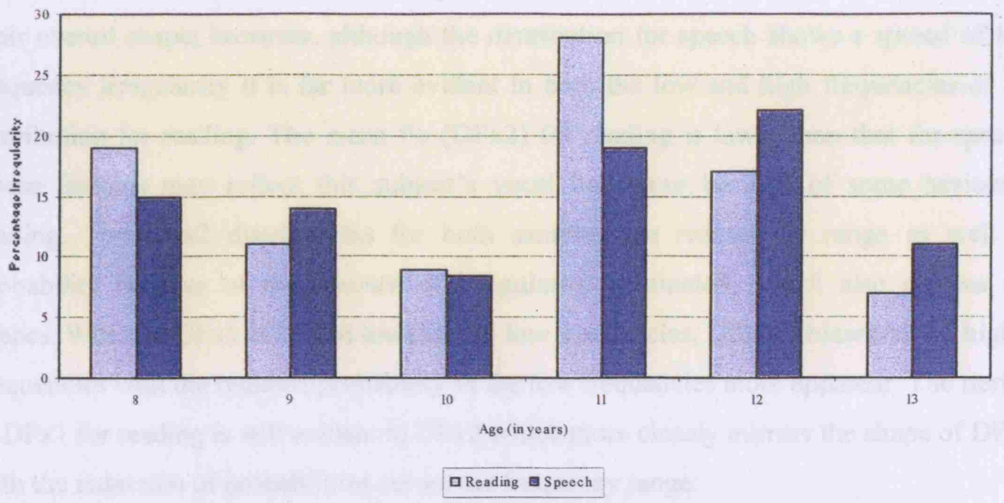


Fig 38 The average values of percentage irregularity derived from reading and speech for each age group.

Caution must be exercised in interpreting the results for such a small sample, but the lower percentage irregularity values for reading at ages nine and ten years would be consistent with development in terms of improved articulatory skills, neuromuscular function, vocal abilities and confidence. A features which may be attributed to maturation is the increase in irregularity in speech at age 12years; the lower irregularity at age 13 years may be related to breath control.

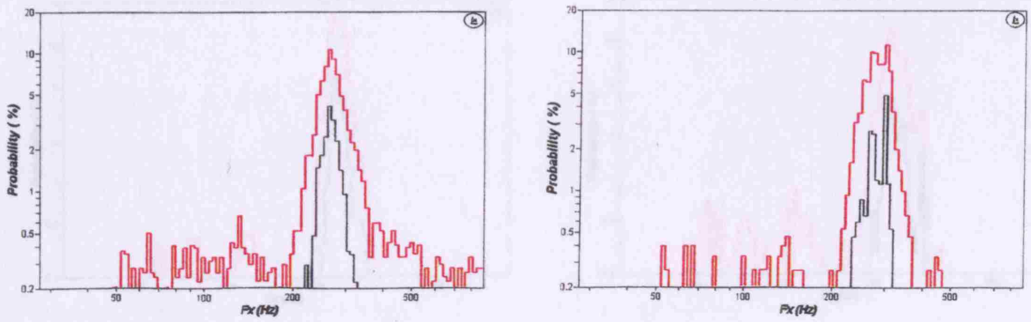
High values (over 20%) were found for both reading and speech in seven subjects (Subjects. 13.14.17.30.31.32.40).

Distributions for a selection of subjects are reviewed.

10.3.1 High percentage irregularity in reading and speech.

Subject 40 Age 8.01 years

Irregularity: Reading - 38% Speech- 35%



Reading Speech

Diagram 18 (i)

Both DFx1 distributions show a tiering towards the modal peak and are very similar in their overall shape; however, although the distribution for speech shows a spread of low frequency irregularity it is far more evident in both the low and high frequencies of the distribution for reading. The mean Fo (DFx2) for reading is lower than that for speech. These features may reflect this subject's vocal behaviour because of some hesitation reading. The DFx2 distributions for both samples are reduced in range as well as probability because of the amount of irregularity eliminated, which also defines the shapes. Whereas DFx1 is loaded towards the low frequencies, DFx2 is biased to the higher frequencies with the reduced probability in the low frequencies more apparent. The tiering in DFx1 for reading is still evident in DFx2 which more closely mirrors the shape of DFx1 with the reduction of probabilities across the frequency range.
The CFx crossplots reflect the narrow range, with diffuse scatter.

				Octave Range	
Material	DFx1	DFx2	CFx	DFx1	DFx2
Reading	AH	AH	N.D	2.6	0.4
Speech	AL	AH	N.D	1.6	0.3

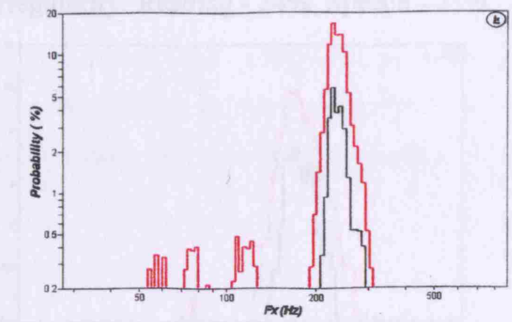
Table 55(i) Comparison of classification of Fx distributions and crossplot and the difference in the mean Fo in octaves for subject 40

Comparison of the Fo values shows that the mean, mode and median are all close in both reading and speech.

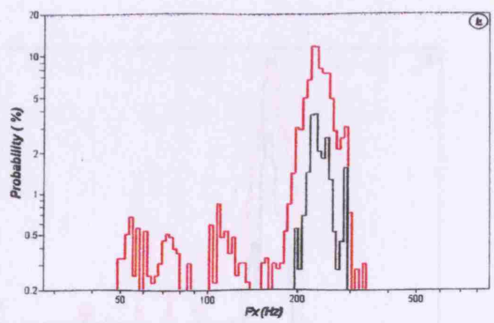
Although perceptually this subject had a weak, and slightly breathy voice his vocal quality had been attributed to his personality as a quiet, rather shy and apprehensive little boy who was regarded as having a 'small' voice. However, he did subsequently develop vocal problems which threatened his future in the choir.

<u>Subject 30 Age 9.79yrs</u>

Irregularity; Reading - 23% Speech - 33%



Reading



Speech

Diagram 18 (ii)

This subject, as well as developing vocal problems at a later stage, also had a rather plump neck; however, this is equally pertinent to both reading and speech. Both values are higher than average with more irregularity evident in speech than in reading, although the Fo values are close. The modal DFx2 values for reading and speech are the same; the difference between the mean values for speech (DFx1 and DFx2) reflects a spread of low frequency creak in DFx1.

Comparison of Distributions					
				Octave Range	
Material	DFx1	DFx2	CFx	DFx1	DFx2
Reading	AH.N	AH.N	N.D.P.	1.36	0.33
Speech	AL. W. EH	AL.N	N.D	2.01	0.5

Table 55(ii) Comparison of classification of Fx distributions and crossplot and the difference in the mean Fo in octaves for subject 30.

DFx1 Both distributions show low frequency irregularity with a greater probability evident in speech. The distribution from reading is narrow, tapering up to a discrete peak. Both are asymmetrical and slightly biased to the low frequencies. The DFx from speech shows essentially the same modal peak configuration but has an extra high peak. Both DFx2 histograms are significantly scaled down reflecting the high levels of irregularity and are broadly comparable apart from the secondary high frequency mode and a slightly higher probability of high frequencies in speech than in reading. The CFx crossplots are broadly similar with a small area of density with diffuse scatter; the pattern of scatter is the same but is more contained in the crossplot for reading.
Perceptually this subject had slightly breathy vocal quality; although the choirmaster and singing teacher had judged his voice as 'normal'.

Subject 32. Age 9.39yrs

Irregularity: Reading - 24% Speech - 21%

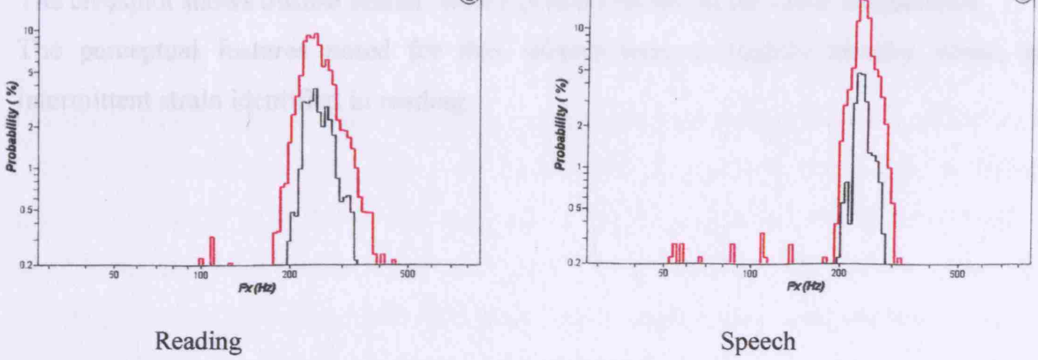


Diagram 18 (iii)

The sample size for speech is small; however, the two values are close which suggests the result is valid. All values (mean, mode and median) are close.

Comparison of Distributions					
				Octave Range	
Material	DFx1	DFx2	CFx	DFx1	DFx2
Reading	AH	AH	A.D.P	1.23	0.56
Speech	SN	A.N.EL	ND	0.75	0.36

Table 55(iii) Comparison of classification of Fx distributions and crossplot and the difference in the mean Fo in octaves for subject 32.

The speech range is narrow (DFx2: 0.36octave). DFx1 is broadly symmetrical with some incidental low frequencies at intervals over a broad frequency range. Both the high and low frequency slopes of the DFx1 distribution are tiered with the probability slightly more in the high frequency range. DFx2 is asymmetrical with a bias to towards the high frequencies. The probability around the middle frequencies creates a very defined peak, and there is a small low frequency peak.

The crossplot reflects the narrow range, with diffuse scatter, more evident in the lower frequency area.

Although there is a difference of 1.3 S/T between the mean values for reading and speech, (the value for speech is the lower), the difference between the lowest values of the ranges is only 0.3 S/T, (similarly the value for speech is the lower). This suggests that this subject's speaking voice is sitting towards the lower end of his range, (the difference between the highest values of the ranges is 2.7 S/T, with the higher range of frequencies used in reading).

The DFx1 distribution is similar in shape over a wider range with a bias towards the higher frequencies. DFx2 shows a fairly even elimination, although proportionately less in the lower frequencies.

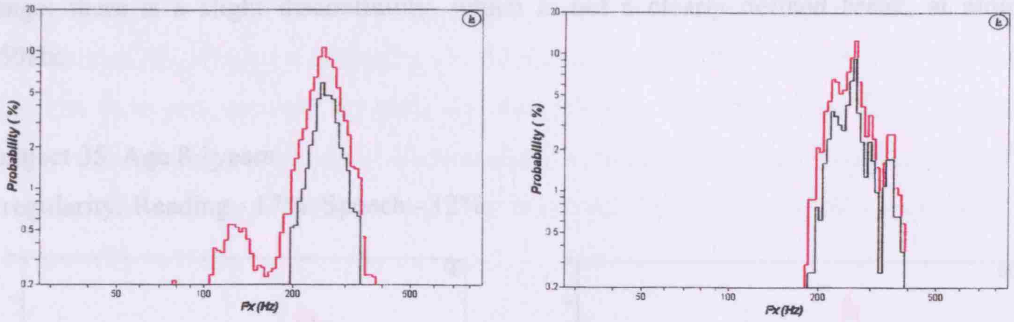
The crossplot shows diffuse scatter, with a parallel spread in the lower frequencies.

The perceptual features noted for this subject were a slightly breathy voice, with intermittent strain identified in reading.

10.3.1.1 Higher percentage irregularity in reading than in speech.

Subject 11. Age 11.89years

Irregularity; Reading - 13% Speech - 5%



Reading Speech

Diagram 19 (i)

The difference between the mean Fo values (DFx1 and DFx2) is 13Hz (0.9 S/T) for reading, and 6Hz (0.4 S/T) for speech.

Reference to the data for the range values shows the greatest difference is between the lowest value of the range for reading with 84Hz (8.9 S/T) eliminated from DFx1. The difference between the lowest values in the range for reading and speech for DFx2 is 3Hz (0.2 S/T), compared to a difference in the highest values of 37Hz (1.9 S/T).

Fundamental Frequency Values - Range					
				Difference	
Material		DFx1	DFx2	Hz	Semitone
Reading	Lowest	124	208	83.9	8.9
	Highest	316	315	1.1	0.1
Speech	Lowest	200	211	11.5	1.0
	Highest	350	352	1.9	0.1

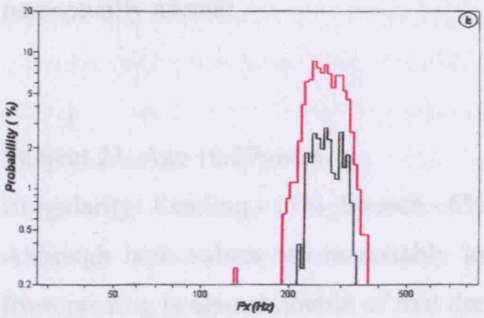
Table 56 Comparison of the lowest and highest values of the Fo range derived from reading and speech, showing the difference between the values for DFx1 and DFx2 in Hz and S/T, (Subject 11).

The most notable feature is use of the low frequencies in reading which is reflected in a bi-modal distribution. The main distribution of the DFx1 histogram is broadly symmetrical; DFx2 is slightly biased towards the high frequencies; which, taking account of both the highest Fo value for speech, and the elimination of the lower values from DFx1 for reading, would suggest that those lower values were inappropriate. However, perceptually no remarkable features were identified in either reading or speech; an element of creaky voice was identified in both but was not considered abnormal.

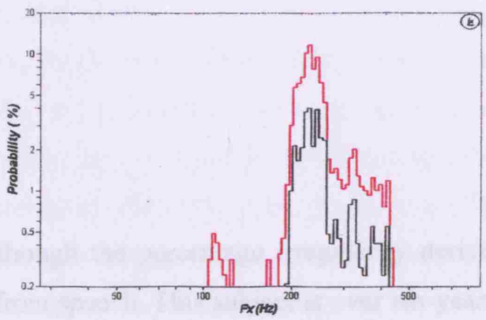
The crossplot derived from speech is unremarkable; there is a diffuse scattering of irregularity across the frequency range, increasing in the lower frequencies, (at around 180–240Hz). The crossplot derived from reading is longer, reflecting the wider frequency range, but the greatest area of irregularity is centered above 200Hz over nearly a 100Hz range; there is a slight discontinuity, which is not a clearly defined break, at around 150Hz.

Subject 35. Age 8.1years

Irregularity: Reading - 17% Speech - 12%



Reading



Speech

Diagram 19 (ii)

Comparison of Distributions					
				Octave Range	
Material	DFx1	DFx2	CFx	DFx1	DFx2
Reading	S	SN	N.D	0.7	0.5
Speech	AH.W	AH.W	W.D	1.04	0.92

Table 57(i) Comparison of classification of Fx distributions and crossplot and the difference in the mean Fo in octaves for subject 35.

The percentage irregularity for both materials is below 20%; however consideration of the values alone is misleading because it does not reflect the difference between the materials, (28.5%). The distribution histograms are very different.

Both the DFx1 and DFx2 histogram derived from reading are compact and broadly symmetrical. The low and high frequency slopes for the DFx1 histogram are tiered, with slightly more probability in the lower frequencies; there is no single peak, with three small peaks and the highest frequency peak is rather more prominent. DFx2 is scaled down with multiple peaks and a small low frequency peak. There is a difference of 1.5 S/T between the modal values from DFx1 and DFx2. There is diffuse scatter around the core diagonal of the crossplot, which is spread more in the lower frequencies.

In contrast, the histogram derived from speech shows a spread of irregularity, more evident in the upper frequencies, with an isolated peak in the lower frequencies. DFx2 is comparable, albeit scaled down, with only the low frequency peak, and a small area of low frequency probability that was integral to the main distribution, eliminated.

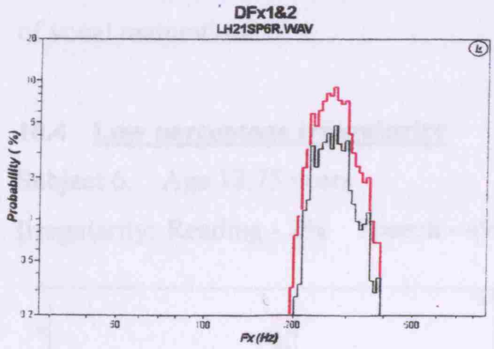
The crossplot is wider and less compact, with only a small area of density between approximately 200 – 270Hz, and a spread of scatter over the lower frequencies.

Perceptually, the vocal qualities for speech and reading also differed. Whilst it is a statement of the obvious to describe a child's voice as 'childish', it is evident that some children do sound younger for their age than others; this subject was noted to sound younger than his age, particularly when reading. Although there were features of breathy, creaky qualities in speech this was inconsistent and the overall quality was considered perceptually normal.

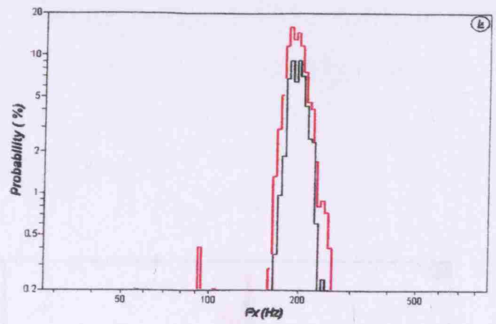
Subject 21. Age 10.29years

Irregularity: Reading - 11% Speech - 6%

Although both values are reasonably low, although the percentage irregularity derived from reading is almost double of that derived from speech. This subject is over ten-years-old so it may be assumed that he is proficient reading.



Reading



Speech

Diagram 19 (iii)

Comparison of Distributions					
				Octave Range	
Material	DFx1	DFx2	CFx	DFx1	DFx2
Reading	AL.W	AL.W	A MS	0.73	0.65
Speech	N AH	N.AH	N L	0.4	0.32

Table 57(ii) Comparison of classification of Fx distributions and crossplot and the difference in the mean Fo in octaves for subject 21

The mean, mode and median values for each type of material are close; however, the difference between the mean values for reading is 77Hz (5.9 S/T) higher than the mean for speech. The highest value of the range in speech (DFx2) is practically the same as the lowest value (DFx2) in reading; this may suggest that by starting to read in the upper frequencies of the range, frequencies above that were less appropriate, with a higher irregularity; (the difference between the highest values for reading and speech is 126Hz (7.7 S/T)).

The DFx1 distribution histogram for speech is asymmetrical with a slight bias towards the upper frequencies with a small co-joined peak at the top of the range, and a small isolated low frequency peak at approximately 90Hz which is not sufficiently significant to affect the overall range values. The DFx2 histogram is narrow and comparable in shape, with the exclusion of a small range of frequencies at the upper limit.

The crossplot has a small area of density relating to the narrow DFx2 distribution and the scatter is mainly in the lower frequencies, parallel to, but away from the core diagonal.

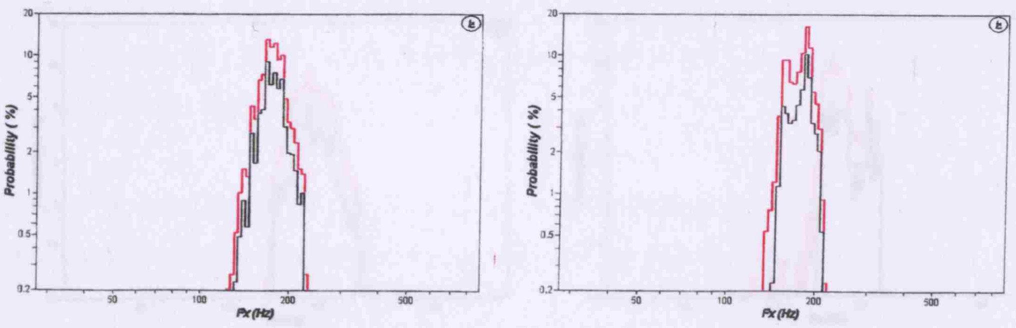
The distribution histograms derived from reading are of a similar configuration, but extending over a greater range, with a more prominent bias to the upper frequencies. The difference between the highest frequency of each distribution (DFx1:DFx2) is only 6Hz (0.3 S/T), with the most obvious reduction in probability at approximately 250 - 270Hz.

Although there were no outstanding features identified on perceptual evaluation, the session notes refer to an intermittent breathy quality and query whether this is indicative of vocal maturation.

10.4 Low percentage irregularity

Subject 6. Age 12.75 years

Irregularity: Reading - 2% Speech - 4%



Reading Speech

Diagram 20. Histograms showing low percentage irregularity

At the age of 12.75 years, it might be expected that this subject would be demonstrating features of vocal function resulting from maturation; however, this is not evident from the quantitative analyses and although vocal creak was identified perhaps the most relevant observation was that he demonstrated very good breath support.

Comparison of Distributions					
				Octave Range	
Material	DFx1	DFx2	CFx	DFx1	DFx2
Reading	S.A	A.A	A L.	0.52	0.5
Speech	S.N	S.N.	N.D	0.44	0.4

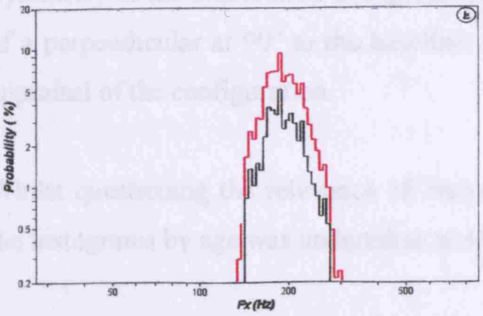
Table 57(iii) Comparison of classification of Fx distributions and crossplot and the difference in the mean Fo in octaves for subject 6.

The mean, mode and median values are all close, (i.e. DFx1 and DFx2 for the same material, and between materials), although the range is marginally wider for reading; (0.5 octave compared to 0.4 octave). The lowest frequency of DFx2 for reading is 148Hz, compared to 152Hz for speech (4Hz. 0.5semitone). The highest frequencies used are 209Hz (reading), and 202Hz (speech); a difference of 7Hz; 0.6 S/T.

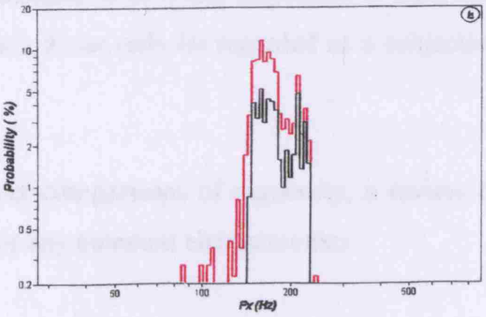
The congruence between the histograms is close for both materials. The high frequency slope of the histogram derived from reading has a perpendicular rise into tiers up to three small and fairly even peaks. The low frequency slope is tiered with a small peak on each level. The crossplot is fairly compact with a small amount of scatter around the core diagonal which is rather more prominent in the mid range. The histogram derived from speech is rather more rectangular with a more defined peak around the mid range. The crossplot is narrow consistent with the reduced frequency range, and likewise has a small amount of scatter but this is more apparent in the upper and lower frequency area.

10.5 Irregularity in subject experiencing voice change

Subject 4. Age 13.08years



Reading



Speech

Diagram 21 Histogram for subject experiencing voice change

Comparison of Distributions					
				Octave Range	
Material	DFx1	DFx2	CFx	DFx1	DFx2
Reading	W.AS	A.AL	A.D	0.77	0.75
Speech	A.AL	A.S.MH	A.D.L	0.67	0.6

Table 57(iv) Comparison of classification of Fx distributions and crossplot and the difference in the mean Fo in octaves for subject 4

The mean, mode and median values for both materials are close. The difference between the mean values (reading and speech) is 23Hz; 2.2 semitones. The difference between the lowest value of the reading and speaking ranges (DFx2) is only 5Hz (0.5 S/T), compared to a difference of 30Hz (2.1 S/T) between the highest value of the ranges. Therefore, although the lowest values in the ranges are close, the higher values which give rise to the wider range, are only used in reading.

The configuration of the distribution histograms differs. The DFx1 histogram derived from reading is asymmetrical, biased towards the low frequencies, with perpendicular rises to both the high frequency and low frequency slopes, tapering off in tiers. There is one more prominent central peak which is still apparent in DFx2 which has a comparable configuration reflecting the degree of irregularity.

The congruence between the DFx1 and DFx2 histograms derived from speech is close, however the tail of low frequencies, and the very small peak are eliminated in DFx2.

The high frequency rise is perpendicular in both DFx1 and DFx2 . Both histograms show multiple peaks and a rather erratic pattern of high frequency peaks; which may reflect features of instability in the voice which were not discernible perceptually.

Symmetry of the distribution histogram was evaluated from visual inspection of each side of a perpendicular at 90° to the baseline; as such it can only be regarded as a subjective appraisal of the configuration.

Whilst questioning the relevance of inter-subject comparisons of regularity, a review of the histograms by age was undertaken to look for any common characteristics.

10.6 Features of age groups

The features noted were not necessarily identified for all subjects, and the number of subjects in each age group is small, nonetheless they may be indicative of common characateristics.

10.6.1 *8 YEAR AGE GROUP*

Histograms for this age group were essentially cone shaped and were similar for reading and speech although the histograms for speech were usually narrower.

Asymmetry was biased to the high frequencies with the high frequency profiles rather more spread than the low frequency slope.

The low frequency profiles of DFx1 show small unevenly distributed steps, with both high and low profiles starting with a short vertical rise graduating at approximately a 45degree angle to the x axis.

The DFx2 histograms show a slight squaring off at the base.

10.6.2 *9 YEAR AGE GROUP*

A review of the histograms of the 9-year-old subjects identified a great variety in the distributions. The features noted are (i) broadening of the range of values in the middle of the range; (ii) the low frequency profile of the histograms of speech are steeper than those from reading.

10.6.3 *10 YEAR AGE GROUP*

The difference between the histograms for reading and speech with the low frequency slope for speech steeper than for reading remains apparent for the 10-year-old subjects, A subjective over-view suggests a move towards the a greater probability of the low frequencies.

10.6.4 *11 YEAR AGE GROUP*

The histograms for the 11-year-old subjects show flattening of the apex. High frequency peaks are more defined compared to the tiering of the high frequency profile observed in the histograms of the younger subjects. These histograms are asymmetrical and skewed to the low frequencies.

10.6.5 *12 YEAR AGE GROUP*

The histograms show similarities with those for the 11-year-old subjects with the low frequency slope changing shape to show an increased probability of the low frequencies.

10.6.6 *13 YEAR AGE GROUP*

The number of subjects in this age group is too small to allow any generalisations. The features noted are (i) The low frequency profile for DFx2 is perpendicular with fewer tiers; (ii) all distributions are asymmetrical with a low frequency skew.

The features noted are not connected to percentage irregularity, but the probability of frequencies may be linked to age related changes.

To explore whether there were any common characteristics associated with a given percentage irregularity, the results were grouped in bands of percentage irregularity. No common features or trends were identified and this did not prove a useful exercise.

10.7 Summary

10.7.1 Reliability of Data

The findings of any study have to be considered in the context of the reliability of the raw data. The recordings made for this study were not made in ideal conditions and some of the high irregularity values may reflect a recording artefact. If the quality of the recordings was affected because the gain control had been set to a sustained vowel, (when the laryngeal posture would be expected to be steady), and not for reading, speech or singing, all the recordings would be comparably affected.

The order in which tasks were undertaken was, vowels, reading, singing tasks and conversation. It is possible that the electrodes may have loosened over time; it would be expected that the voice use differed according to the tasks. The fact that some children, particularly the younger ones may have been less confident reading, and may have felt more relaxed for the casual conversation, is pertinent. This highlights the importance of relating measurements to the perceptual impression.

Notwithstanding these considerations some robust findings are emerging.

- Differences in the percentage Fx irregularity for reading and speech indicate this aspect of vocal function is influenced by task

- Inter-subject comparison is less relevant than individual characteristics and trends. There are clusters of speakers with comparable characteristics; however, the small number of subjects in each cluster preclude rigorous statistical treatment.

- Visual appraisal of the histograms indicates that a more detailed quantitative statistical evaluation of the discrete changes in the histogram shape, using measures of skew and kurtosis, may indicate a pattern of voice use related to vocal maturation which is not reflected in measures of Fo mean, mode and range.

- The results have not demonstrated any obvious trends in percentage irregularity in relation to age. The ranges of percentage irregularity within each group are too broad to be useful and do not demonstrate the relevance of inter-subject comparisons.

- The results support the reference by Baken and Orlikoff (2000) regarding the loss of a "sense of the quality of the vocal sample" resulting from the advent of computerised data acquisition and calculation, and highlight the multidimensional nature of the voice. The findings reported in this chapter demonstrate the importance of placing any one aspect of vocal function within the context of all the interacting factors.

- Similarly Fourcin and Ptok (2003) state that *"simple mean values of critical parameters are not capable of conveying the importance of many aspects of voice.."* and, with reference to the closed phase ratio crossplots (CQx) that *"the structure types... tell far more than their mean Qx values..."* The results of measures of the closed phase of vocal fold vibration are also reported.

10.8. <u>Temporal Irregularity in Singing</u>

The subjects of this study are distinguished from other children by their lifestyle as choristers and their singing skills. Inspection of the percentage temporal vocal fold irregularity evident from analyses of the samples of singing, demonstrates that the values for irregularity derived from singing are typically lower than those for either reading or speech. This would be consistent with better breath control, and more auditory attention and monitoring of voice production than is usually used in speech.

The percentage CFx irregularity for singing is presented and compared to the irregularity derived from reading and speech.

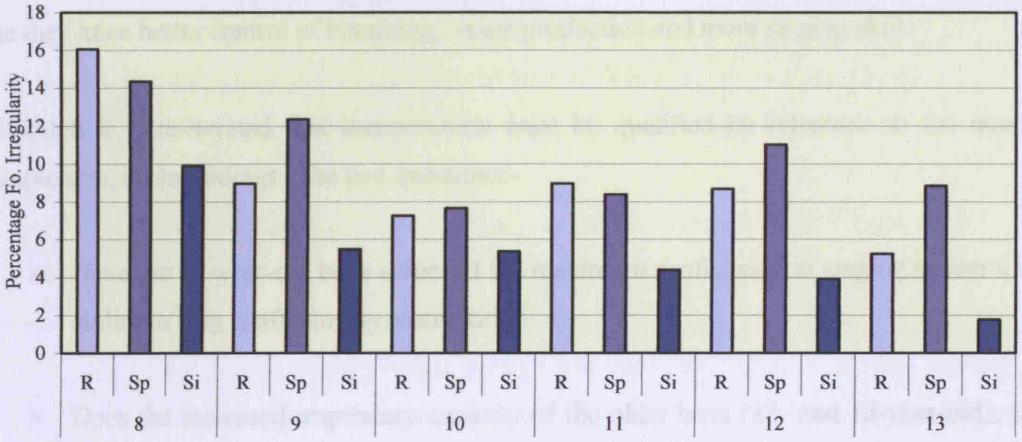


Fig 39 Average percentage CFx irregularity values for reading (R), speech (Sp) and singing (Si) for each age group shown in ascending order (in years), from left to right.

As applies with all the group data, average values can be misleading and presentation of the data showing the values for individuals within each age band makes apparent that the average values can be distorted by one or two outlying values.

Lowest and highest values for each age group:

8 years 1.6 – 25.4: 9 years 0.7 – 14.3: 10 years 0.5 – 30.3

11years: 0.5 – 23.4 12 years 0.4 - 16.7: 13 years 0.3 - 5.0

Inspection of the number of subjects with low percentage irregularity shows that low irregularity occurs mostly in the 11-year-old age group.

Age (in years)	Sample size	% Irregularity					
		<1%	<3%	<5%	5 - 10%	10 - 20%	>20%
8	10	0	3	3	3	3	1
9	15	2	7	9	3	3	0
10	24	6	14	15	4	4	1
11	21	9	14	15	2	3	1
12	18	6	10	14	2	2	0
13	4	2	3	4	0	0	0

Table 58 The number of subjects in each group with Fo % irregularity in bands up to 20%.

The proportion of subjects with high irregularity values is higher in the younger subjects, and lowest in the 12-year-old and 13-year-old subjects, although it may be expected that at these ages there would be more irregularity associated with maturation it equally applies that at this age they have better control of breathing, voice production and more singing skill.

Although it is re-iterated that interpretation must be qualified by reference to the overall sample size, these findings raise two questions:-

- Have the 11-year-old boys achieved the maximum proficiency in singing before their ability to sing is affected by maturation?

- Does the increased respiratory capacity of the older boys (12- and 13-year-old), and the enhanced performing skills compensate for any physiological instability associated with growth of the laryngeal apparatus?

10.9 Observations

A review of the range of values across all tasks (speech, reading and singing) shows that although the irregularity values are typically lower for singing than for speech and reading, there are no clearly identifiable age related trends or patterns of change; these findings highlight the extent of variation between individuals.

EXAMPLES OF RESULTS FOR INDIVIDUAL SUBJECTS

Only two subjects had a higher irregularity when singing than when speaking and reading.

Subject 17 (age 11.49yrs): although all values were close:- Speech and Reading, both 12%; Singing -13%.

Subject 38 At 9.48yrs the irregularity value is 14%, marginally higher than that for reading(13%), but lower than for speech (22%); whereas at 10.48yrs the value is higher than both speech and reading, (8% compared to 3% for both speech and reading).

Subject 8 The percentage irregularity of the speech sample was higher at 12.28yrs than at both 11.29yrs and 13.29yrs: (10% compared to 5% and 4% respectively). The irregularity in singing was likewise higher (4% compared to 1% and 0.3% respectively), but this value was still lower than any of the values for speech and reading at ages 11.29ys, 12.28yrs and 13.29yrs..

Subject 10 Age 12.09. The percentage irregularity in speech is high (34%) compared to reading and singing, (4% and 3% respectively).

Subject 12 The percentage irregularity values increase over the two year period (10.83yrs – 2%; 11.81yrs – 2%; 12.87yrs – 3%), although all values are relatively low.

Subject 15 In contrast, shows a value of 11.14% at age 10.29yrs falling to <1% at 12.14yrs.

Subject 21 The irregularity in speech and reading was greater at 11.34yrs (13% and 17%) compared to the value at 10.29yrs (6% and 11%), but the percentage irregularity from singing was less, (11.34yrs – 5%; 10.29yrs – 7%).

Subject 40 At 8.01yrs the irregularity in speech and reading 5was very high (36% and 38%) compared to the irregularity in singing, (15% - although this was still relatively high). However at 9.99yrs, although the irregularity in speech is still high (26%), the value for singing has fallen to 7%.

10.10 Fundamental Frequency Range

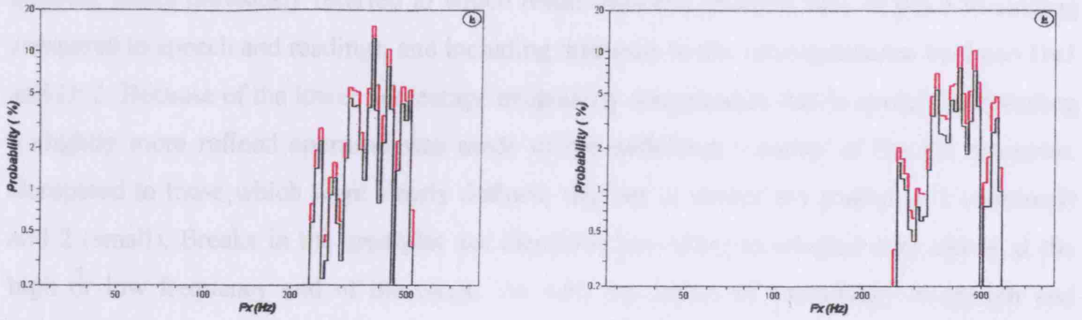
10.10.1 DFx Distribution Histograms

As previously noted the key features of the DFx distribution histograms are the symmetry, the range, the number of modal peaks and the congruence of DFx1 and DFx2, and, for the CFx crossplot, the range, the density and the scatter. There are aspects of singing to a set tune which distinguish the characteristics of the distribution histograms from those derived from speech and reading because in principle, the pitch range is defined and relatively consistent. (Although the range of the tune is twelve S/T, it is noted that the DFx2 octave ranges varied from the smallest of 0.5 to 1.3.)

10.10.1.1 *FEATURES OF HISTOGRAM DISTRIBUTIONS*

The probability of the use of high/low frequencies is determined by the music and the distribution of frequencies within the tune, and in principle this should govern the resulting shape of the distribution. In speech and reading asymmetry may be indicative of a bias (towards either high or low frequencies), whereas in singing any loading, or diminution of low or high frequencies over and above the probabilities appropriate to the material, may reflect an inability, (or unwillingness) to achieve the target pitch.

The histogram distributions derived from speech and reading are typically pointed with one prominent modal peak, as the probability of the mean and modal Fos is greater than the lesser used high and low frequencies. In singing, however, the probability of the frequencies across the range may be comparable resulting in a squarer configuration with a series of modal peaks. Diagram 22 (i)



(i) (ii)

Diagram 22 Examples of histograms derived from singing

In speech and reading there is typically a continuity between the frequencies because of intonational 'gliding' contours within the range giving a solid base to the histogram, whereas in singing the notes are typically more sustained with a higher probability of a greater number of ranges of frequencies results in a more fragmented histogram. In example (ii) (Diagram 22) although there is continuity in the Dx1 histogram across the frequency range, this is not reflected in the Dx2 histogram giving an impression of breaks at three frequency range compared to example (iii, Diagram 22) which has a very clearly defined base and multiple peaks across the frequency range. These distributions are difficult to categorise.

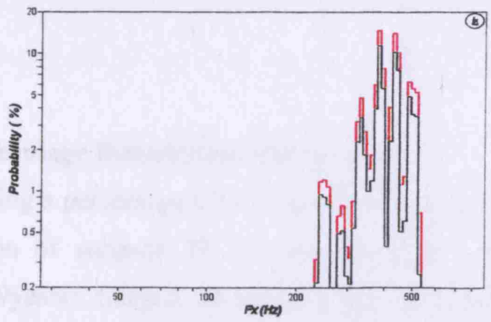


Diagram 22 (iii) Example of a histogram derived from singing.

Whereas in speech and reading there is a single distribution with a dominant modal value, in singing, (depending on the tune), the high probability of another, or more than one other range of values is not unusual. Therefore interpretation of the distributions has to consider the relationship of secondary and tertiary modes to the primary mode and the nature of the tune. The system of classification applied to the analyses derived from speech and reading has been revised, with the revision of omitting reference to additional peaks (because of the feature of multiple peaks previously referred to which result from the different uses of pitch in singing compared to speech and reading), and including reference to the correspondence between Dx1 and Dx2. Because of the lower percentage irregularity compared to that in speech and reading a slightly more refined appraisal was made of the definition / scatter of the Cx crossplot. Compared to those which were clearly defined, degrees of scatter are graded as 1 (minimal) and 2 (small). Breaks in the crossplot are identified according to whether they occur at the high or low frequency end of the range. As with the aspect of irregularity in speech and reading, there are no clearly identifiable features or trends; therefore individual histograms are inspected.

<u>Subject 7 (Age 12.18years)</u>

This distribution shows a correspondence in the DFx1: DFx2 distribution in the low and mid frequency range but lesser probability of the higher frequencies reflected in DFx2.

The difference between the lowest value of the Fo range values, (DFx1 and DFx2) is 1 S/T; the difference in the high frequency values is only 0.2 S/T whereas the differences between the high frequencies of the range (DFx1 and DFx2) for subjects 15(age 10.29yrs) and 16(age 11.9yrs) are 5.4 and 3.4 S/T respectively. The modal values (DFx1 and DFx2) are identical, (487Hz).

10.10.2 Low Percentage Distribution Histograms

All the subjects presenting a percentage CFx irregularity value below 1% are over 10years of age, with the exception of subjects 29, (% irregularity 0.7. age9.12years), and 23 (% irregularity 0.9. age9.49years). Subject 29 shows a loading towards the upper Fos, but the upper Fo value is amongst the lower values used by this age group, and sits within a speaking range, which may account for this low percentage irregularity. (ie if the subject is singing within a comfortable range; the session notes record that this subject was using more of a 'speaking to music' style).

The distribution histogram for subject 23 is similar (to the one described above) but the lower frequencies are integral to the main distribution; the mean, mode and median values are all similar. This may be indicative of more stability in the lower frequencies in this subject, at this age. The upper frequency is marginally higher; (Subject 23: 408Hz. Subject 29: 386Hz, a difference of 0.9 S/T).

Subject 29 had consistently low irregularity values, (0.7%: 0.6%: 0.5%) which, combined with the upward shift of 1.2 S/T between the ages of 9.12yrs and 11.22yrs may reflect increased singing skills.

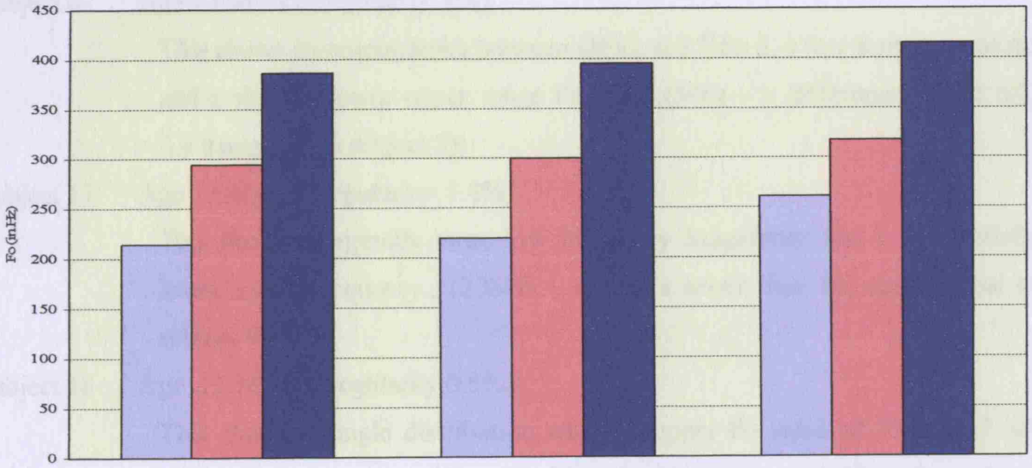


Fig 40 The trend in Fo values (lowest value of range, mean and highest value of range at ages 9.12yrs, 10.22yrs and 11.22yrs for subject 29.

Fo irregularity values below 1% at more than one age were shown in subjects 8, 19, 23 and 27.

Subj. No	Age (in years)	Difference DFx1 : Low Fo of range	High Fo of range	% Irregularity
8	11.29	0.7	0	0.8
	13.28	0.1	0	0.3
19	10.2	0.2	0.1	0.9
	11.15	0.1	0.1	0.9
23	9.49	0.2	0.1	0.9
	10.4	0.2	0	0.4
27	9.79	1.0	0	1.1
	10.81	0.2	0	0.7
	11.2	0.2	0	0.9

Table 59 The difference between the DFx1 and DFx2 values for the lowest and highest Fo range is shown in S/Ts, with the percentage irregularity for the four subjects referred to above.

On visual inspection of the distribution histograms for these subjects high frequency peaks are evident:-

Subject 23 at 9.49yrs and 10.4yrs

Subject 19 at 11.15yrs (a small peak)

Subject 27 at 10.81yrs and 11.12yrs

Subject 8 at 11.29yrs and 12.28yrs. However, at 13.28years subject 8, as well as showing a very low percentage irregularity (0.3%) the upper frequency range is consolidated within the main distribution, with increasing probability in the lower frequencies.

Features of the distribution histograms for subjects age 13years were noted:-

Subject 4 Age 13.08yrs (irregularity 6%)

This shows correspondence between DFx1 and DFx 2, a low frequency peaks and a slightly lower upper range Fo value,(348z – a difference of 0.3 S/T, (i.e.compared to subject 8))

Subject 17 Age 13.42yrs (irregularity 1.4%)

This shows marginally more low frequency irregularity and a substantially lower upper frequency., (238Hz – 6.7 S/Ts lower than the upper value of subject 8).

Subject 18 Age 13.16yrs (irregularity 0.5%)

This shows a single distribution with the upper Fo value of 398Hz; (2 S/T higher than the upper value of subject 8). However at 11.97yrs this subject showed high frequency irregularity with an isolated high frequency mode and an upper frequency value of 816Hz.

Reference to both the CFx crossplot and perceptual judgements is essential to interpret this data. The percentage irregularity value for this subject at age 11.97yrs is 11%. The CFx crossplot shows scatter across the range, consolidated in the upper frequency range, with two discrete areas with a fainter trace almost equating to a break. Perceptually the voice was judged as asthenic with slight pitch breaks only evident in the descant, (which is analysed separately). The session notes from the recording at the age of 13.16years, however, describe the voice as slightly hoarse. Despite this the CFx irregularity value at the age of 13.28yrs was only 0.5%.

These findings raise further questions.

- How useful is inter-subject comparison?
- What percentage of CFx irregularity is indicative of a well-performing voice, compared to the level which reflects an element of dysfunction for the singing task?
- What is the significance of the difference in percentage temporal irregularity between singing, speech and reading in relation to the ability to sing during the period of voice change associated with maturation?

As the subjects are performing together as a group which requires a certain degree of uniformity, it may be argued from the point of view of the Director of Music, that there needs to be a standard which all the choristers can achieve. For the clinician who is helping an individual with a voice problem it is what is normal and appropriate that is relevant, rather than comparisons within a specific group, unless there is some factor which accounts for the differences which can be usefully applied to the clinical care of the performing voice more generally.

Low percentage CFx irregularity is consistent with negligible differences between the DFx1 and DFx2 values, as shown by the following examples.

			Difference DFx1:DFx2 in semitones		
Subj. No	Age	% Irreg.	Mean	Lowest value of range	Highest value of range
32	10.48	0.6	0.1	0.1	1.0
36	11.41	0.7	0	0.7	0
2	12.58	0.5	0.1	0	0
6	12.75	0.6	0.1	0.2	0
18	13.16	0.5	0.1	0.1	0

Table 60 The difference between DFx1 and DFx2 mean Fo, and the lowest and highest values of the Fo range is shown in S/T for subjects with low % irregularity.

10.10.3 Longitudinal comparison of percentage irregularity

Reference to the longitudinal data shows that typically the value derived from the third recording is comparable to or lower than the first recording, and that where the value is either comparable to or higher than from a preceding recording there is no obvious correlation with age.

Subj No.	Recording					Subj No.	Recording				
	Second		Third				Second		Third		
	Higher	Lower	Higher	Lower	Comparable		Higher	Lower	Higher	Lower	Comparable
40				x		20				x	
35		x		x		26	x			x	
23		x		x		27					x
39					x	30		x	x		
33		x	x			28	x				
38	x			x		22		x		x	
34		x	x			15				x	
37		x	x			21		x		x	
31		x		x		12		x	x		
29		x		x		16	x			x	
25					x	8	x			x	
19					x	17		x		x	
36		x		x		11	x				
32		x	x			18		x			
24				x		14		x			

Table 61 The relative increase or decrease in CFx % irregularity between analyses.

These values are reviewed to show the age interval and percentage increase. The small numbers preclude any robust conclusions; however, this aspect of vocal measurement warrants further study with a larger subject group.

Subj. No	Age range (in years)	Age Interval (Months)	% Increase
8	11.29 - 12.28	11.9	3.0
11	11.89 - 12.85	11.5	3.9
12	11.81 - 12.87	12.1	0.6
16	11 - 11.9	10.8	12.2
30	11.09 -12yrs	10.9	1.7
32	10.48 - 11.48	12	0.5
28	10.01 - 11.12	13	3.9
26	9.78 - 10.77	11.9	20.4
33	9.3 - 10.3	12	13.1
34	9.73 - 10.73	12	1.0
37	9.8 - 10.68	10.5	4.5
38	8.47 - 9.48	12	7.5

Table 62 Increase in % CFx irregularity related to time interval between analyses for a selection of subjects.

The difference in values for subjects 12, 32 and 34 is not remarkable whereas it is notable for subjects 16, 26 and 33.

Subj No	Age (in years)	% Irreg.	Semitone Difference DFx1: DFx2				
			Mean	Mode	Median	Low value of range	High value of range
16	11	1.0	0	0	0	0	0.1
	11.9	13.1	1.1	0	0.4	0.8	3.4
	12.89	2.5	0	0	0.1	0.4	0.2
26	9.78	9.9	0.1	0	0	2.5	0.5
	10.77	30.3	0.6	0	0.1	12.8	0.3
	11.69	0.9	0	0	0.1	0.1	0
33	8.32	18.6	0.2	2	0.2	1.3	0.7
	9.3	1.7	0.1	0	0	0.5	0
	10.3	14.8	0.2	0	0.1	4.9	0.6

Table 63 The % irregularity, and difference between DFx1 and DFx2 for a range of Fo values in S/T, for 3 subjects at three ages.

Subject 16 There is an overall lowering of the Fos between the ages of 11years and 12.89 years. The high frequency (DFx1 and DFx2) at age 11 years appears to be unusually high (682Hz) but the percentage irregularity is low and the distribution is very compact, with little scatter on the CFx crossplot, in contrast to the distribution at age 11.9years which is characterized by the spread of DFx1 in the upper frequency range, and diffuse scatter on the crossplot, more apparent in the upper frequency range.

Perceptually this subject was using the falsetto register at age 11 years but was identified as demonstrating good breath support.

Subject 26 The notable feature of the values for this subject is the relatively low Fo particularly at age 10.77 years when DFx2 mean is 1.9 S/Tss lower, and the DFx2 upper range is 2.8 S/Tss lower than the values at 9.78 years. The distribution histogram at age 10.77 years shows an amount of creak with diffuse scatter on the CFx crossplot, marked in the lower frequency range. The session records at 9.78 years and at 10.77 years note that this subject was straining on the lower notes, and for the recording at 10.77 years it is noted that he was "pushing his voice down" and singing below a comfortable pitch. These behaviours are reflected in the very high percentage irregularity value.

At age 11.69 years the distribution histogram is more compact with secondary high and low frequency modes. The low percentage irregularity value suggests there is more stability in the vocal function; however, the session record notes that the upper frequency was weak with a 'speaking to music' style of singing.

Subject 33 This subject was one of the youngest in the study and comments in the session record are useful.

Year 1 (age 8.32 years), his singing voice was described as rough and out of tune.

Year 2 (age 9.3 years), he was again out of tune; features of creak and breathiness were perceived and he was described as 'speaking to music'.

Year 3 (age 10.3 years), he was still singing out of tune, and his voice was perceived as asthenic.

Whereas the percentage irregularity values at ages 8.32 years and 10.3 years were high (19% and 15% respectively, at age 9.3years, when he was described as using more of a speaking delivery, the percentage irregularity was much lower (2%).

10.10.4 High Percentage Irregularity

As shown in the following chart high percentage Fo irregularity values were apparent in subjects in all age groups. Some of these have already been discussed.

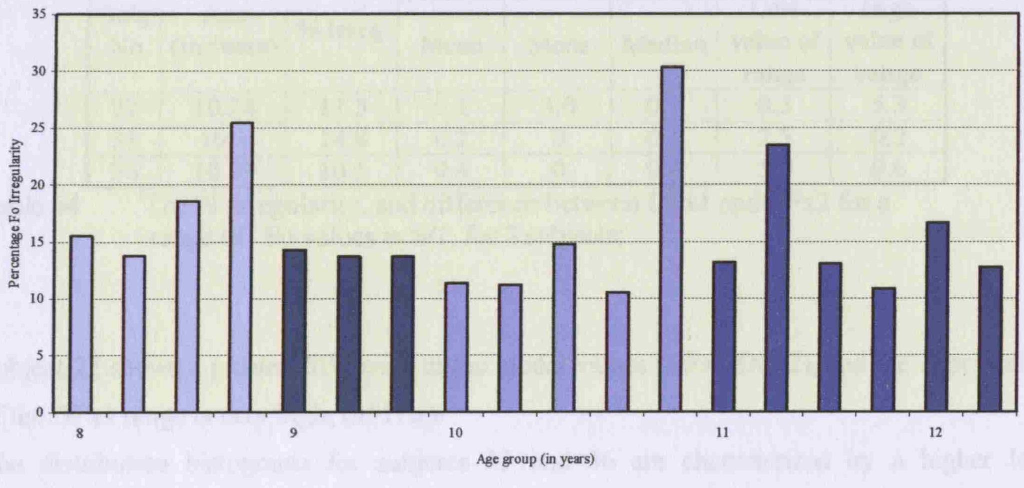


Fig 41 High percentage irregularity values by age group.

Subject 31 (age 8.88 yrs) The irregularity is diffuse but is more concentrated in the lower frequencies with vocal creak in the region of 94Hz.. The DFx1 range is 2 octaves, compared to the range of DFx2 of 0.7 octave.

Subject 33 (age 8.32 yrs) This shows a narrow frequency range (DFx1 0.6 octaves; DFx2 0.5 octaves) with a greater probability of the higher frequency range. This is more apparent in

DFx1; however, the configurations of the distributions compare fairly closely. The probabilities of the frequencies across the range are close with only three peaks, compared to the multiple peaks seen in other examples derived from singing. This may correlate to this subject singing out of tune.

The distribution histograms for subjects 30 (age 9.79yrs); 36 (age 9.38yrs) and 38 (age 9.48yrs) all show the greater probability of the higher frequencies, with similar patterns of scatter away from the core diagonal of the CFx crossplot irregularity in the low frequency range.

In the 10-year-old age group subjects 15 and 26 have been discussed. The distribution histograms for subjects 22, 33 and 36 are similar, although in subject 36 the scatter in the CFx crossplot is more concentrated around the mid and upper frequency ranges, compared to a diffuse spread in subjects 22 and 33.

The values for these three subjects are shown :-

Subj No	Age (in years)	% Irreg.	Semitone Difference DFx1:DFx2				
			Mean	Mode	Median	Low value of range	High value of range
22	10.24	11.3	0.1	3.0	0.1	0.3	5.3
33	10.3	14.8	0.2	0	0.1	2.5	0.2
36	10.39	10.5	0.4	0	0.4	5.0	0.6

Table 64 The % irregularity, and difference between DFx1 and DFx2 for a range of Fo values in S/T, for 3 subjects.

Subject 22 shows a greater difference in the modal values (DFx1:DFx2), and the upper value of the DFx1 range is very high, (811Hz)

The distribution histograms for subjects 33 and 36 are characterized by a higher low frequency value in DFx2 compared to DFx1, which may be indicative of the instability in extension of the lower frequency range.

Subjects aged 11 years

(Subject 9, 11.52yrs; subject 18, 11.99yrs; subject 16, 11.9 year, subject 17 11.49yrs)

Subject 16 has been discussed. The data for subject 18 highlights the rapid change occurring within a 13month period.

Age (in years)	% Irregularity	Octave Range		Semitone Difference		Longitudinal semitone difference	
		DFx1	DFx2	Low	High		
11.99	10.8	1.28	1.26	0.1	0.1	Low	High
13.16	0.5	0.79	0.79	0.1	0	6.7	12.4

Table 65 Comparison of Fo range in S/T and over interval between age 11.99yrs and 13.16yrs for subject 18.

Subject 9 The histogram shows s a small amount of low frequency creak and irregularity up to 300Hz. (This may result from electrode movement which was noted in the session record). The DFx1 and DFx2 distributions broadly correspond; however, the difference in the probability of frequencies is greater in the upper frequency range. The session record notes that the subject strained to reach the upper notes, with indications of pitch breaks in the upper register.

Subject 17 No conspicuous features were noted and the distribution histograms show good correspondence of the main distribution but there is a high frequency secondary mode in DFx1 which, with the exception of two narrow ranges of high frequency is eliminated in DFx2. The octave ranges are DFx1: 1.1; DFx2 0.6 The difference between the lowest Fo is 0.3S/T, compared to a difference of 6.5 S/T in the highest frequency of the range. The CFx crossplot shows the irregularity concentrated in the upper frequencies.

Subjects 1 and 13 are similar ages (12.41yrs and 12.48yrs respectively), but the distribution histograms are differ markedly.

Subject 1 shows a greater reduction of the probability of the high frequencies, with a secondary low frequency mode, and diffuse scatter in the CFx crossplot. Subject 13 shows a spread of high frequencies in DFx1 which is entirely eliminated in DFx2.

Subj. No	Age (Years)	% Irregularity	Octave Range		Semitone Difference	
			DFx1	DFx2	Low	High
1	12.41	16.6	1.9	1.1	10.3	0.3
13	12.48	12..7	1.1	0.7	0.1	4.7

Table 66 Comparison of Fo range in octaves, and difference between lowest and highest values in S/T for subjects 1 and 13.

How useful are such comparisons?

Subject 1 has a lower frequency (DFx2- 265Hz compared to the DFx1 value of 146Hz (10.3 S/T difference). The low frequency values of DFx1 result from the contribution of very small amounts of regular creak, with the main distribution established in the region of 250Hz. There is little difference between the upper values. Subject 13 does not have the extended low frequency range and loses a greater proportion of the high frequencies from DFx1 to DFx2.

Two subjects of particular note are subject 6 (age 12 yrs), and subject 15 (age 12.14yrs). The percentage irregularities are low, (<1%).

Perceptually subject 6 demonstrated conspicuous pitch breaks on all tasks (speech, reading and singing), and subject 15 found the pitch range of the tune difficult. It was noted that perceptually his voice sounded breathy and that there was some strain on the lower notes although he reported that it felt comfortable.

Subj. No	Age (in years)	% Irreg.	Octave Range		Semitone Difference	
			DFx1	DFx2	Low	High
6	12	0.57	0.86	0.84	0.2	0
15	12.14	0.96	0.53	0.53	0.1	0

Table 67 Comparison of Fo range in octaves, and difference between lowest and highest values in S/T for subjects 6 and 15.

There are obvious substantial differences between the values for these two subjects,

DFx1		DFx2	
Mean	10.7 S/T	Mean	10.8 S/T
Upper range	12.6 S/T	Upper range	12.5 S/T

The DFx1 lower ranges are slightly closer (8 S/T); however the higher value of DFx2 is 1.7 S/T higher than the low DFx1 value of subject 6.

10.11 Descant

This study was not rigorously controlled as it was considered more important that the boys felt comfortable and enjoyed the experience. Consequently they were asked whether they wanted to sing the descant; only five (of the total of forty subjects) were willing to do so. The data for these analyses are presented.

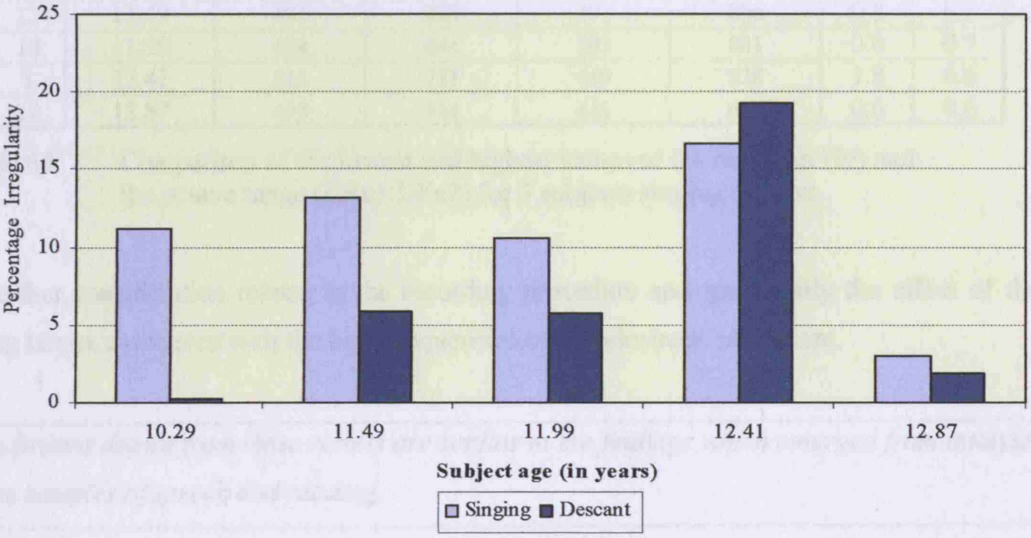


Fig 42 Comparison of the percentage irregularity for singing and descant for 5 subjects. (subject nos. from left to right: 15.17.18.1.12)

Again the number of samples is too small and there is too much variability – despite the fact that they were meant to be singing the same tune - to allow any conclusions to be drawn. The youngest subject to attempt this task was 10.29years and the irregularity value derived from analysis of the descant is substantially smaller than that from the conventional singing. The difference in values is not so great for the subjects aged 11.49years and 11.99years, but is nonetheless a marked difference.

Subjects 1 (age 12.41yrs) and 17 (age 13.42yrs), had a greater percentage of irregularity when singing descant, whereas subject 12 (12.87 yrs) had a lower percentage irregularity on the descant, both values being below 3%. However, significantly in the context of their age and maturity, the descant is pitched slightly lower by subjects 1 and 12. Perceptually both appeared to strain to reach the higher notes; the vocal quality of subject 1 was described in the session notes as 'thin' and 'sounding like a girl'.

Subj. No	Age (in years)	Lowest value of range		Highest value of range		Octave Range	
		DFx1	DFx2	DFx1	DFx2	DFx1	DFx2
15	10.29	585	871	587	871	0.6	0.6
17	11.49	491	828	497	806	0.8	0.7
18	11.99	494	841	502	841	0.8	0.7
1	12.41	215	751	419	638	1.8	0.6
12	12.87	408	614	411	606	0.6	0.6

Table 68 Comparison of the lowest and highest values of the range (in Hz) and the octave range (DFx1:DFx2) for 5 subjects singing descant.

A further consideration relates to the recording procedure and specifically the effect of the rising larynx associated with the high frequencies on the electrode placement.

Conclusions drawn from these results are similar to the findings which emerged from analysis of the samples of speech and reading.

- The contrast in the percentage CFx irregularity values for singing, compared to those for speech and reading demonstrate that this aspect of voice quality is influenced by task.

- An emerging finding is that there is a closer relationship between reading and singing, than speech and singing, indicative of the effect of using the voice to perform, compared to the relaxed, and less "supported" spontaneous use.

- Group data and inter-subject comparisons provide broad indicators of levels of temporal irregularity but, in the absence of information on factors which govern differences (such as biometric data), it is more informative to inspect individual characteristics.

- Interpretation of results should be reviewed in the context of the recording procedure (e.g.electrode placement) and individual behaviours. This latter is particularly relevant as it has to take account of (a) training, and (b) strategies used to achieve the target pitch.

- Although the number of samples is too small to enable rigorous statistical treatment the point at which the effect of training enables the production of regular voicing in the context of the influence of maturation on the speaking and singing voice is critical and warrants further investigation.

- Visual interpretation of the distribution histograms is important, and suggestive, but larger numbers would be needed for a quantitative study (of kurtosis, for example), to be valid.

- The comments by Baken and Orlikoff (2000), and Fourcin and Ptok (2003) regarding the sense of quality of the sample, and the structure types, cited with reference to the irregularity in reading and speech, have equal application to singing.

10.12 Irregularity of the closed-open phase

The singing data for this study was reviewed in the context of the work by Howard et al (1990), and that of Barlow and Howard (2002: 2005). It is therefore noted that:-

- The subjects of the present study qualify as young trained singers in terms of the definition proposed by Barlow and Howard (2002). Whilst they are referred to as professionals, there are crucial factors which distinguish them from the adult professionals, specifically that their aptitude and abilities are neither established nor predictable because of age related changes; if there is even a transient deficiency, it can lead to vocal strain which is then reflected in the way the vocal apparatus functions. The contact phase is particularly relevant to the performing voice and therefore whether the increased closed quotient is the consequence of training, or of forcing is therefore pertinent.

- The total number of subjects in the studies reported by Barlow and Howard is much larger than for this study (Study 1. (2002): 76 females; 51 males; Study 2 (2005): data derived from recordings of 256 subjects – subjects in the study reported 74 female; 71

male). However, the number of male trained subjects under 12 years in study 1 is 20 (results reported for 17), and the number of trained male subjects (unchanged voices) in study 2 is 30. By comparison the numbers for this study are 40 subjects in year one of the study, of whom 37 were aged 12 years and under - slightly more than in either of the other studies.

- The potential to cross-reference findings is limited by the differences in materials used; the reading sample in the present study is more substantial, (Abberton 2005), and the singing sample less controlled; both are relevant considerations in the interpretation of findings.

- Visual inspection of the QxFx plots derived from connected speech, reading and singing did not reveal the findings of the 2002 and 2005 studies referred to, but supported the finding of a wide range of CQ values in reading, (Howard, 1990). The 2002 paper by Barlow and Howard states that the spoken text was only used to determine the mean speaking pitch; the 2005 paper by the same researchers does not specify whether this also applied; however, as the study is based on the same raw data and is related to singing training, it is assumed that the findings relate to the sung material only. Findings for speech and reading comparable to those derived from singing scales are not to be expected.

- The vocal behaviours for singing a hymn or song can be expected to differ significantly from those applied to singing a scale because of the influence of articulation, volume, timing, emphasis, and breath control.

The data for the present study was first evaluated against the patterns presented by Barlow and Howard, although the degree of stylisation of the patterns or whether the shapes are abstracted from interpretation of areas of concentration, is not evident. (Appendix 11)
If it is assumed that the patterns are stylised from the QxFx plots the patterns most apparent in the data for the present study were those identified by Barlow and Howard as Group 1 and Group 4.

Other recurring patterns were identified.

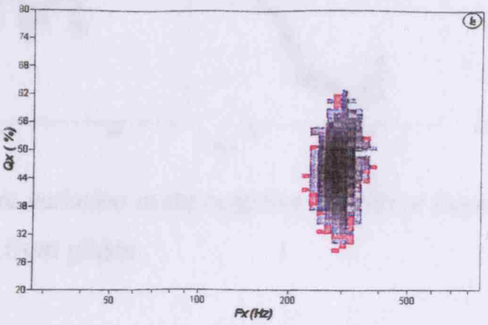


Diagram 23(i)

This shows a wide range of CQ values creating a more perpendicular shape. Although this could be interpreted as broadly similar to the Barlow and Howard pattern 2 with a great range of CQ values, it would be misleading to present it as that because of the extent of variation in the closed quotients.

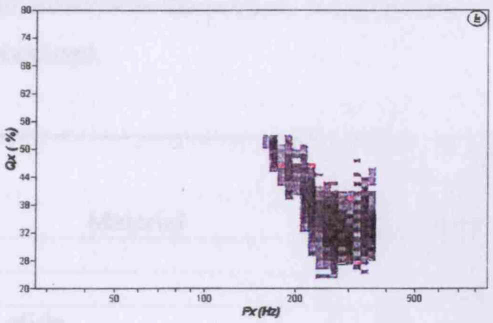


Diagram 23(ii) Shows a greater range of CQ values in the lower frequencies with a wide range of values in the mid and high frequencies. This could be broadly interpreted as comparable to Barlow and Howard pattern 1, but would not reflect the broad range of CQ values in the mid and high frequencies.

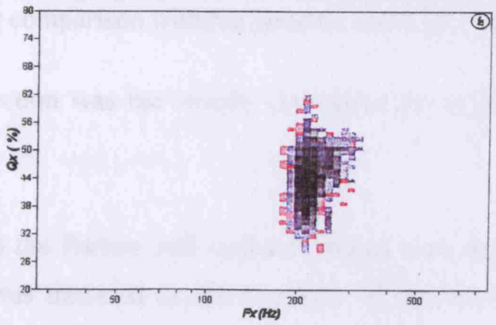


Diagram 23(iii) In this example there is a broad range of frequencies in the lower frequencies, tapering to a narrower range of higher CQ values in the mid and high frequencies.

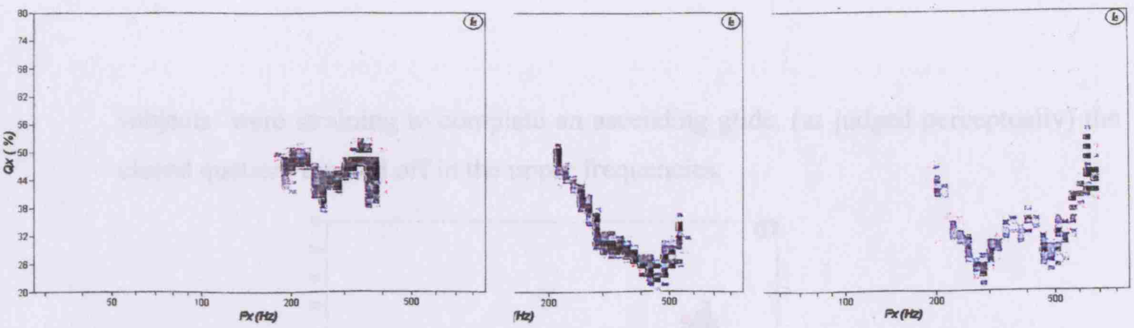


Diagram 23(iv) More variation in the negative – positive slopes of the patterns was evident in the Qx plots derived from glides.

The prevalence of eight patterns (the 5 presented by Barlow and Howard and the further three described), is summarised in relation to age groups and materials, (Appendix 12).

To assess the influence of material, and whether the patterns identified by Barlow and Howard were evident in the same material in the subjects in the present study, a sample of data derived from other tasks was examined.

Material	Sample size	
	No. of subjects	No. of Samples
Scales*	22	39
Arpeggios	20	28
Ascending glide	20	39
Ascending and descending glide	4	5
Descending glide	17	27
Glide mid range ascending	17	29
Glide mid range descending	17	24
*ascending, descending, and ascending and descending		

Table 69 The type of singing tasks and the number of subjects and samples used for comparison with the patterns identified by Barlow and Howard.

Because the data collection was not strictly controlled the influence of various factors was evident.

- The subjects in the Barlow and Howard studies were asked to breathe as necessary; although this was intended to allow control of the volume it conceals the effect of diminishing breath support on the vocal fold vibratory behaviour and therefore on the closed quotient. Relating the QxFx pattern derived from analysis of an ascending glide in the present study, to the perceptual judgement, demonstrated that when subjects were straining to complete an ascending glide, (as judged perceptually) the closed quotient tapered off in the upper frequencies.

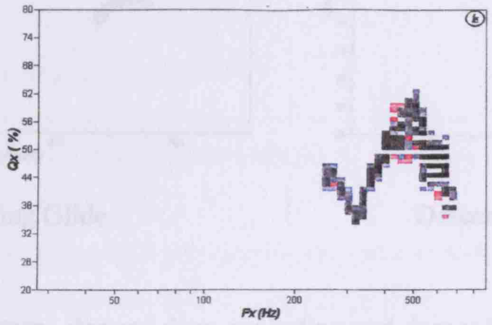


Diagram 24(i) An example of an ascending glide, with the closed quotient tapering off in the upper frequencies. The subject was judged perceptually to be straining to complete the glide.

- The timing and rhythm of the performance influences the closed quotient; ie whether the notes were smooth and slightly sustained, or were more staccato, and the overall rate at which the scale was completed. Similarly when the last note in the scale was slightly sustained the Qx value was higher than when it was finished abruptly.

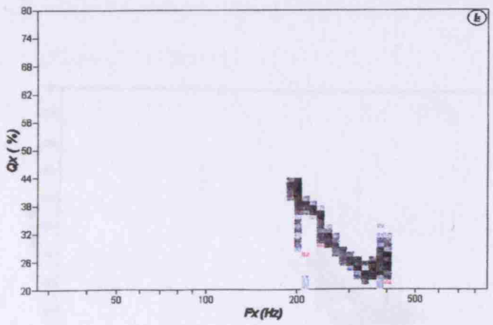
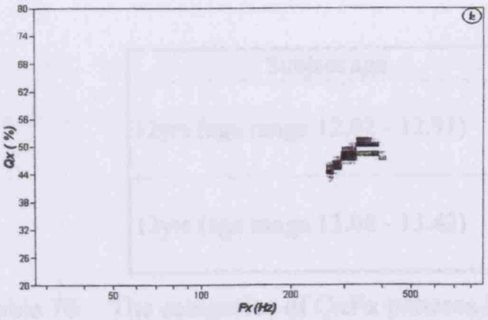
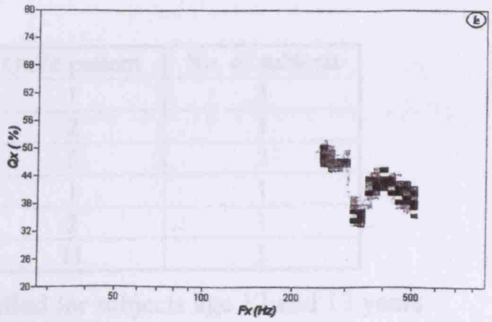


Diagram 24(ii) An example of a descending glide with an increase in the Qx value as the last note was sustained slightly

The QxFx pattern derived from ascending and descending glides differ according to influenced by the direction of pitch change. (Diagram 24(iii))



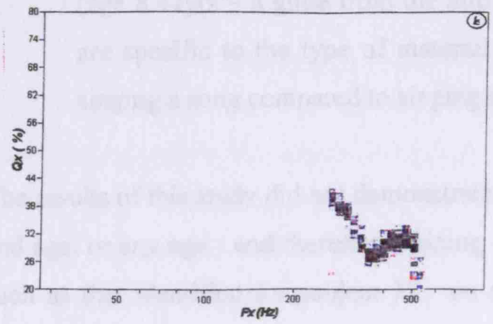
Ascending Glide



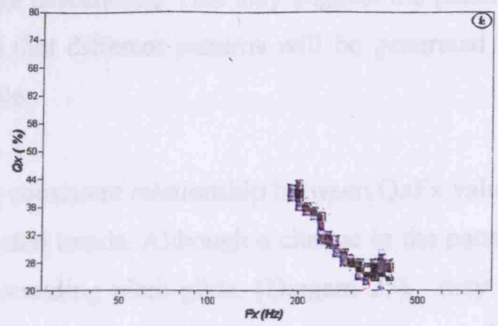
Descending Glide

Diagram 24(iii)

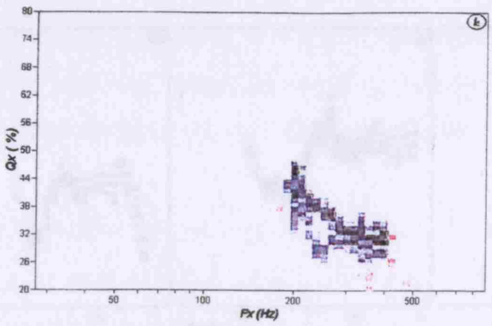
- The QxFx patterns derived from ascending and descending glides reflects the pattern of each independently; this is evident in the following examples.



Ascending Glide



Descending Glide



Ascending and Descending Glide

Diagram 24(v)

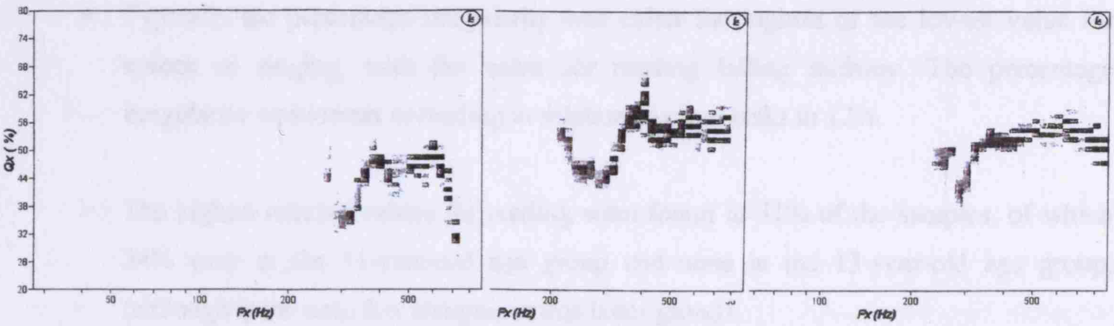
- In general the subjects in this study did not demonstrate an influence of training in the QxFx pattern for sung material.

Subject age	QxFx pattern	No. of subjects
12yrs (age range 12.02 - 12.91)	1	5
	2	1
	5	2
13yrs (age range 13.08 - 13.42)	1	1
	2	1
	11	1

Table 70 The categories of QxFx patterns identified for subjects age 12 and 13 years

- The pattern associated with the developing voice (Barlow and Howard. 2005, Group 2A) was identified in two subjects; subject 29 (age 9.12yrs but only for a glide from the mid range descending and age 10.22yrs for an ascending glide), and subject 38 (age 8.47yrs – a glide from the mid range descending. This may suggest the patterns are specific to the type of material and that different patterns will be generated by singing a song compared to singing a scale.

The results of this study did not demonstrate any consistent relationship between QxFx values and age, or any age - and therefore training - related trends. Although a change in the pattern such as that identified for subject 37, on an ascending pitch glide, (Diagam 25), may be interpreted to demonstrate a changing vocal behaviour with a higher closed quotient used in the upper frequencies, because of the extent of variation throughout this subject group such interpretation cannot be considered reliable.



(a) (b) (c)

Diagram 25 Subject 37 at ages 8.75yrs (a); 9.8yrs (b), and 10.68yrs (c)

These findings again demonstrate the spectrum of intra and inter-subject variation, and that the results are influenced by task and by relatively subtle differences in performance. This suggests that assessment should be based on a range of tasks and that the degree of spontaneity, or conversely control of performance, may substantially influence the results.

10.13 Relationship between CFx and CQx values

Measures of CFx and CQx percentage irregularity were compared to explore whether there is any relationship between them or whether they are independent variables. Other factor to be considered are whether the relationship is are task related or age related.

10.13.1 *PERCENTAGE CFx IRREGULARITY*

The results suggest that the percentage irregularity is lowest for the singing task, and highest for the spontaneous speaking task. The relationship of CFx values according to the task was identified by ranking the values (3- highest; 1-lowest).

- The relationship of lowest percentage irregularity in singing and highest in speech was found in 41% of samples; 29% of this group were in the 11-year-old age group, compared to 8% in the 8-year-old age group. Only 4 subjects demonstrated a consistent relationship of relative lowest irregularity in singing and relative highest in speech in all the 3 analyses..

- Typically the percentage irregularity was either the highest or the lowest value for speech or singing, with the value for reading falling midway. The percentage irregularity was lowest in reading in relation to other tasks in 12%.

- The highest relative values for reading were found in 31% of the samples, of which 34% were in the 11-year-old age group and none in the 13-year-old age group, (although there were few samples in this latter group).

- Only 6% had the highest percentage irregularity in singing and only 2% had the lowest percentage in speech.

10.13.2 PERCENTAGE CQx IRREGULARITY

The highest CQx percentage irregularity values were evident in reading and speech, compared to singing, (this refers to the relationship of the values between tasks and does not refer to a high or low value).

- The percentage irregularity was higher for singing than for either reading or speech in 14% of the samples; 30% of this group were age 10years.

- The lowest values for singing were found in 25% of the samples. 29% of this group were age 11 years compared to 4% in the 8-year-old group.

- The highest relative value occurring in speech was found in 27% and in reading in 29%. The lowest value occurring in speech was found in 21%, and the same percentage occurrence was found in reading.

The variability that has characterised all the data in the present study was also evident in these measures. Inspection of the data to determine any consistent patterns revealed the same pattern of relationship for CFx and CQx values in 19% of the samples; only 1 subject showed these patterns in all analyses over the three sets of recordings.

Comparison of the relationship between the CFx and CQx values derived from singing demonstrated the lowest percentage CFx irregularity and highest CQx (ie both compared to the other values for each subject) in 24%; whereas both CFx and CQx were higher in singing than in other tasks in only 5%.

A CQx value that was lower in relationship to the other values with a CFx value that was relatively higher was found in 9% of speech samples and was not evident at all in the samples of singing. This suggests that a relatively high percentage CFx irregularity is not necessarily associated with a relatively low percentage CQx in singing.

Reference has been made to the finding that the effect of singing training is evident in changes in the closed quotient. A notable finding of this study is that where it was possible to identify a pattern of change over time this was evident in all tasks. This suggests that these changes are not specific to singing and may be related to other developmental features such as increased breath support and neuromuscular maturation rather than, or as well as training.

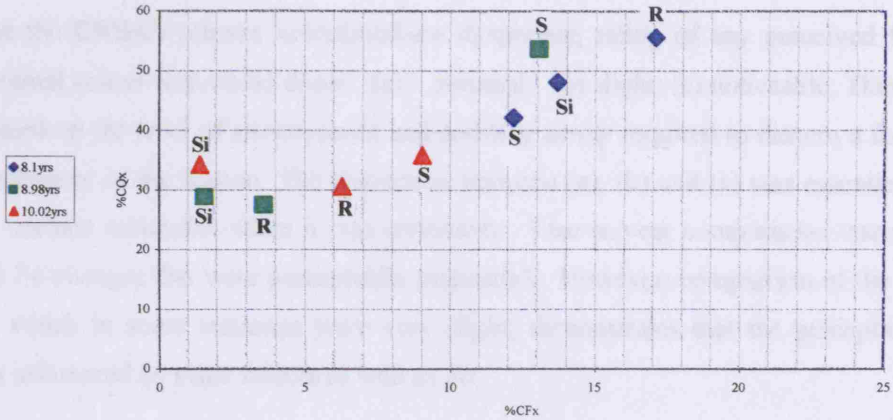


Fig 43(i) Relationship between CFx and CQx. for all materials. (reading (R), speech (S), and singing (Si). Subject 35

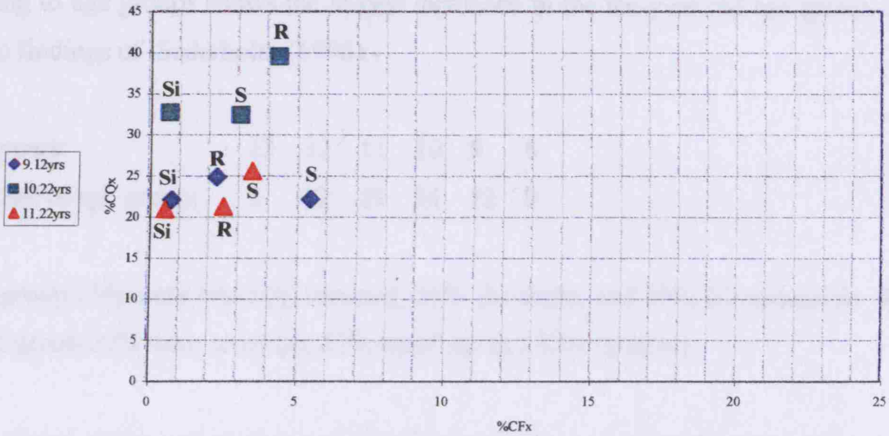


Fig 43 (ii) Relationship between CFx and CQx. for all materials. (reading (R), speech (S), and singing (Si). Subject 29

10.14 The relationship between measures of irregularity and perceptual evaluation

The subjects of this study were perceived, both by themselves and others to have 'normal' sounding voices, therefore the scope for perceptual evaluation was limited. Application of the GRBAS scale enabled a broad appraisal of overall voice quality and was supported by observations of other features pertinent to voice use which were included in the perceptual evaluation used by McAllister (2003), (Hard glottal attack; vocal pitch). This evaluation was based on listening to the recorded data of speech and reading and cross-referenced with notes made at the time of the recordings. Any features specific to a task were noted, but otherwise the comments were generalised. (Appendix 13).

Because the GRBAS scheme accommodates dysphonia, rating of any perceived feature in these normal voices was scaled down: (a) – minimal: (b) slight: (c) noticeable. These criteria were based on the level of attentiveness and auditory acuity required to discern a feature and the consistency of the feature. The distinction between (a), (b) and (c) was essentially that a feature became noticeable when it was consistent. Year to year comparisons were made to identify Fo changes that were perceptually discernible. However; comparison of the mean Fo values, which in some instances were very slight, demonstrates that the perception of the voice is influenced by other factors as well as Fo.

Although the qualities identified did not fall outside subjective perceptions of normal voice quality an element of breathy quality was evident in 43% of the samples. The distribution according to age groups shows the largest incidence in the ten-year old age group, consistent with the findings of Sederholm (1996):-

Age in years:	13	12	11	10	9	8
Percentage of age group:	5	22	19	31	12	9

Of this group 15% were rated (a) minimal; 53% (b) slight, and 30% (c) noticeable. In the 11-year-old group 50% were rated (a); 12% rated (b) and 37% rated (c).

A hard glottal attack was noted in 37% of the samples and appeared to be related to rather forceful articulation of consonants; possibly a consequence of vocal training with an emphasis placed on distinct and somewhat exaggerated articulation.
Other notable features were (i) that a lowering of Fo and (ii) a change in resonance, was discernible from perceptual year-to-year comparisons.

Relating these judgements to the measures of closed quotient irregularity for reading and spontaneous speech did not reveal any obvious relationship between breathy quality and lower CQx values; however this may be accounted for by the fact that the degree of breathy qualities was slight and typically inconsistent.

The CFx and CQx values for those subjects identified as having some degree of breathy quality were inspected to explore whether there was any relationship between these variables.

CFx values were rated as low (<10%); mid (<20%) and high (>20%).
CQx values were rated as low (<20%); mid (<50%) and high (>50%).

%CFx	%CQx	% of Group
Low	Mid	60
Low	Low	3
Low	High	3
Mid	Mid	8
Mid	High	8
High	Mid	3
High	High	14

Table 71 The combinations of % CFx and CQx ratings and relative incidence

A low CFx (<10%) was associated with a CQx of between 20- 50% for 60% of this group.

There was no direct relationship between these results and chronological age, although all subjects rated 'high-high' were in the 12-12.5age range, with the exception of one subject; this subject was very tall for his age (above 97th centile).
Perceptual evaluation of the singing voice was based on a clinical, not a musical perspective.
The highest CQx values were derived from the samples of descant singing.

Subject no.	8	12	1	17	18	15
Age(in years)	11.29	12.87	12.41	11.49	11.99	10.29
Mean Fo	399	474	515	625	644	738
CQx%	35.06	48.65	79.25	63.7	62.83	60.23

Table 72 Mean Fo (in Hz) and percentage CQx irregularity derived from samples of descant singing.

10.15 *SUMMARY OF RESULTS OF VOICE QUALITY MEASURES*

Measures of irregularity (temporal (cycle by cycle irregularity, CFx), contact quotient (variations in the duration of the contact phase of the vocal fold vibratory cycle, CQx) are important to an understanding of the voice and perceived voice qualities.

In the absence of published data on measures of CFx and CQx in children these results provide a foundation for future work. Evaluation of the analyses is based qualitatively on visual inspection and interpretation of the configuration of the DFx distribution histograms and QxFx plots, and quantitatively on the percentage irregularity values (CFx and CQx).

Comparison of the DFx1 and DFx2 distributions histograms reveals more information on the probability of frequencies than can be deduced from the statistical result of analyses. As well as the feature of symmetry, (for example, a bias towards the high or low frequencies in DFx2 was more obvious in the younger subjects, with the distributions for the older subjects showing more symmetry) inspection indicates that a more detailed appraisal of the configuration (from measures of skew and kurtosis) will provide important information on subtle changes in probability indicative of reducing the use of the higher frequencies and moving towards a preference to use lower frequencies.

A key factor in appraising the QxFx plots is the manner of speaking, reading or singing, for example, whether a subject replenishes their breath support, draws on residual air to sustain phonation, or stops abruptly, can alter the pattern of the Qx plot. The results indicate a relationship between Qx and other aspects.. Differences were identified according to whether a pitch glide was ascending, descending, or ascending and descending.

The results of the present study do not support the findings of Barlow and Howard (2005), and demonstrate intra and inter-subject variability.

CFx and CQx percentage irregularity values were reviewed independently and in relation to each other.

This confirmed that a relationship with task exists; and that typically the percentage CFx irregularity value is highest for spontaneous speech and lowest for singing; and that the highest CQx percentage irregularity values were found in reading and speech.

These results were related to perceptual evaluation; however the scope for perceptual evaluation was limited by (a) the fact none of the subjects were considered to have abnormal voice qualities, and (b) the appropriateness of applying perceptual evaluation schemes designed to evaluate dysphonic voices to a normal child voice. Consequently although no obvious relationship was found between CQx percentage irregularity values and perceived breathy voice quality a rider to this is that the breathiness identified was neither consistent nor abnormal.

No direct relationship was identified between these results and chronological age.

CHAPTER XI DISCUSSION AND CONCLUSIONS

11 Introduction

Clinical research can be descriptive, or experimental; both types can contribute to the provision of an explanation of a phenomenon, each involves exploration of various kinds to answer research questions. Lowe (1993) writes that *"The final choice of design will depend on the current level of knowledge, on the resources available, on whether the purpose of the study is primarily to observe or to intervene and on the likely access to and co-operation from relevant populations."*

This study is essentially descriptive, focusing on the quantifiable aspects of a special vocal function. The objective of undertaking such a study was to obtain information to support the care of choristers in respect of voice use. It is founded on a clinical perspective and intends to highlight the complexity of this subject, embracing the intricacies of voice production in speech and singing further complicated by the variability associated with the physical and psychological process of maturation. However, exploration does not necessarily lead to definitive answers - the process of exploration frequently provokes more questions. Whereas some of these questions can be addressed in future work using the data derived from this study, the relevance of studies in evaluating others is questionable, for example:-

- The subjects of this study may all be considered as 'normal', in terms of their physical and physiological development, (as demonstrated by the results of the biometric measurements), and academic abilities. Their lifestyle, however, is very different from that experienced by the majority of children in the U.K. This raises the question – should they be regarded as examples of the normal child population?; are measures derived from studies of other groups of 'normal' children relevant to the results for this group?

  It may be argued that as the aspect studied, (i.e.vocal function), is that which distinguishes them from children who are not choristers, comparison of certain parameters may not be useful.

  If the topic is approached in terms of voice production only, the question has to be extended to ask what is it that distinguishes vocal function in choristers from vocal function in other children; is it solely the ability to perform? and, if so, is that exclusively the consequence of training, or are there characteristics that enable one child to sing more easily than another? is there a predisposition, (physical or psychological)?

- If features of vocal function relate to training it leads to the question, what aspects of voice production are altered by training and is there carry-over of behaviours learned in singing, to speech?
- How does the vocal function of trained choristers compare to that of the child who simply enjoys singing without singing in any structured environment?

In recent decades researchers have called for more data, and studies on larger subject groups; arguably, of more relevance than the size of the subject group, is uniformity of data collection. The findings of the present study will be discussed in relation to the original key research questions. A large amount of data has been analysed; the results show trends but are characterised by variability throughout.

11.1 Discussion of the research questions.

What are the quantifiable characteristics of changes in fundamental frequency of male adolescent choristers age 8years– 13years?

The merit of comparison of measures of Fo mean, and range derived from reading and spontaneous speech and singing with available data for children is limited because of the diversity of methodologies, materials and analyses used in different studies.

Notwithstanding this, the results from the present study fall within the range of values reported by other researchers, and are within less than one S/T of the average of all available data. Taking account of factors previously referred to regarding the conditions for data collection for the present study and the relatively small sample sizes, these results appear robust.

The average values reflect the irrefutable age-related lowering in mean Fo. However the mean Fo values for individuals within each age group show substantial variation, (up to 4.8 S/Tin reading and 4.5 S/T in speech). Where this results from an obvious difference in voice use, (for example the use of a character voice when reading), an extraordinary part of the sample can be extracted and the mean Fo can be verified by analysis of the remainder; however, where it reflects the consistent voice use, and appears perceptually appropriate, judgements based on interpretation of a range of measures and perceptual evaluation will be more relevant than comparison with group average Fo values.

The progression of the lowering of mean Fo is not consistent, with the lowering between ages of 11-12years greater than between the ages of 8-11years, and with a further and larger lowering between the ages of 12-13years. This is evident in both reading and spontaneous speech samples. Individual subjects demonstrate a lowering in mean Fo over the course of the three recordings but in some instances the mean Fo was higher than the result for the previous year, (as also found by Bennett (1983) and Whiteside (1999)). This is not remarkable - typically the differences were small and could be accounted for by behavioural factors such as familiarity with the environment and the task, and overall confidence – but may be pertinent to the time interval between analyses. Although the results of this study support the finding of Bennett that age-related changes can be detected over a one year period from year to year comparisons of group data, the fluctuation demonstrated by individuals suggest that analyses within a shorter time interval would enable useful monitoring of intrasubject variability which Whiteside suggested may be related to maturation of the central nervous system.

Another feature of the group average results is that the average mean Fo derived from the spontaneous speech sample is lower and the Fo range narrower than the reading sample; this difference is greater in the 11-13year old group, than in the 8-10year old group. There is currently no published comparative data but this is typical of the vocal behaviours found in adult subjects.

The change in the mean Fo results from the changing probability of frequencies both at the top and bottom of the range. The average of the lowest values in reading and speech shows a consistently downward but uneven trend. The notable feature is that whereas the lowest Fo in reading fall by 1.74 S/T between age 11-12years (compared to less than one S/T in the age groups 8-11years), and by 1.55 S/T between the ages of 12-13years, results derived from spontaneous speech show a lowering of 4 S/T between the ages of 12-13years. This is pertinent to voice use and the implications for singing. The older subjects were obviously more confident reading and their level of reading skills enabled them to judge the breath support required according to the sentence length – essentially reading aloud may be compared to performance voice use. The behaviours differed in spontaneous speech allowing the voice to function at its natural level.

The variability within age groups found in mean Fo is obviously evident in the range values. The differences between the lowest and highest of the low values of the range was up to 8.8 S/T for reading and up to 9.3 S/T in spontaneous speech. The variability in the values for the highest Fo of the range was greater, with the difference between the lowest high value and the highest high value of up to 12.6 S/T in reading, and 14.7 S/T in spontaneous speech. The greatest variability occurred in the 10-11year old group When the data for this group was split into two groups (10yrs– 10.48yrs; 10.5yrs-10.9yrs), it demonstrated that the variability is greatest in the highest Fo of the range, and that this variability was more evident in the 10.54-10.9-year-old group than in the10.01-10.48-year-old group in both reading and speech. This may be indicative of instability in the upper frequencies starting at around 10½years and supports the argument that a one-year interval between analyses does not identify subtle changes that are emerging. However, interpretation of all data has to take account of the different behaviours resulting from concurrent educational and social development and suggests that assessments of vocal function should be supported by a more comprehensive evaluation, (ie including reading and speaking skills).

Relating the results to those derived from singing introduces more factors than just different material with a greater number of variables to be considered in determining methodology.

- Should subjects sing alone, or with an accompaniment? Williams et al (2005) observed more stability in the Lx signal when a chorister was singing with *"another individual"*.

  Comparison of recordings of subjects singing alone and with an accompaniment, (instrumental and /or vocal) would be useful.
- Should subjects sing as if they are giving a performance? Emphasis was placed on the subjects in the present study feeling comfortable; they were not asked to make any particular effort.

  Comparison of both ways of singing would be useful, but for the purpose of this study an informal approach was appropriate.
- Should subjects rehearse the material they will undertake? The subjects in the present study were familiar with the hymn used. Assessment of sight reading may give further information if unfamiliarity with either or both the words or the tune is distinguished, but is of limited relevance unless subjects are regularly required to sight read when performing.

Unless rehearsal is based on a criterion (such as three trials of a vowel and the third one is used), the number of rehearsals and the subsequent choice of sample used is arbitrary. This is demonstrated in the present study by the different result for a subject who was recorded twice in the same session, (Mean Fo values differed by 4.6 S/T; the range differed by 1.6 S/T)

- Should the way a task is undertaken be controlled? The subjects in the Barlow and Howard study (2005) were asked to repeat a task according to the researchers' perception of fluctuations in volume and breath control.

  The subjects of the present study were given a C tuning fork to guide their pitch but beyond that they simply sang. Consequently some subjects sang out of tune and the Fo range varied from that of the music; however, their performance clearly reflected their competence and indicates that vocal difficulties may be masked when they are singing as a group.
- Should 'exceptional' Fo values be included in analyses of group data? (this is also relevant to data derived from reading and spontaneous speech).

The mean Fo values derived from singing demonstrated the same overall lowering as the other materials, (5.4 S/T between the ages of 8years and 13years), with notable differences in the trend. After an initial drop of 1.1 S/T from age 8years to 9years, the average mean Fo became higher by 2 S/T between the ages of 9years and 12years, before falling between the ages of 12years and 13years by 6.3 S/T.

Although the overall change is comparable for both the average of the lowest values of the Fo range, and the highest values, (5.9 and 5.4 S/T respectively) the trends differ.

For the lowest Fo of the range, the value is lower at 9years than at 8years, but is higher at 10years than at 9years, and higher again at 11years. The values at ages 11years and 12years are comparable (within 0.13Hz) before lowering by 7.5 S/T.

The trend for the highest values of the Fo range differs after age 11years with the average value at age 12years 1.3 S/T lower prior to a further drop by 5.4 S/T between the ages of 12years and 13years. The highest values in the ranges increase by marginally more than the lower values indicating an upward shift.

The notable aspects of this result are (i) that these changes were demonstrated despite the fact that the subjects sang the same tune and (ii) the move towards the higher Fo is counter to the trend related to maturation. The different mean Fo values may have resulted from the subjects singing within a comfortable range, or because they did not have a target pitch. The upward shift may result from increased neuromuscular control combined with a more developed respiratory mechanism and greater auditory skills.

The proposal to assess vocal function for descant singing was not pursued when it became apparent that only a few subjects were happy to sing descant; (total number of samples - 7) There is not a sufficient number of samples by subjects of the same age to allow interpretation of the results, beyond the observation that the both the lowest and highest Fo in the range used by the youngest subject (age 10.29years) were higher than those used by the older subjects. The most pertinent finding was the general unwillingness to sing descant.

The results of this study provide useful data, but the crude measures of Fo mean and range do not illustrate the way in which these changes are occurring, as stated by Fourcin and Ptok (2003):- *"simple mean values of critical parameters are not capable of conveying the importance of many aspects of voice.."* and *"the structure types* (of the CQx crossplots) *tell far more than their mean Qx values."*

There is no available data on measures of skew and kurtosis of the Fx distribution histograms for samples of child voice. A broad appraisal of the shape can be made by visual inspection to identify changes in the probability of the Fos. The results discussed above suggest that subtle changes in the probabilities will be evident before there is a substantial effect of these changes on the Fo measures and will provide invaluable information for clinicians and singing teachers responsible for the care of these children.

Are the quantifiable characteristics of changes in measures of fundamental frequency exclusively governed by physiological change or is there evidence of the influence of training?

This question is approached by reference to the measures to the two types of irregularity; temporal (Fo irregularity (CFx)) and contact quotient irregularity (CQx).

MEASURES OF TEMPORAL IRREGULARITY

There is no published data on this aspect of voice quality measures for children.

Some very high values were found in the present study for reading and spontaneous speech, and some very low values were found in samples of singing; this result was predictable and consistent with the different vocal behaviours demonstrated according to the task. Because of the intrasubject variability it is difficult to account for the high values. The fact that the low values occurred in the singing task (which followed the reading but preceded the spontaneous speech) suggests that the electrode placement and data collection was satisfactory.

There were no obvious features such as dehydration; throat clearing behaviours were noted but were not exceptional in any individual; certain articulatory behaviours which may contribute were more apparent in singing than in either reading or speech, (eg emphatic articulation, friction). If tension/ stress contributed to the irregularity it would likewise be expected that all the results would be comparably affected with possibly a greater effect on singing than on reading and speech. The effect of aggravants applicable to this subject group is that caused by dust and pollution only. Significantly the percentage irregularity values for those subjects found to have some vocal fold abnormality were not remarkable.

The intrasubject variability may be related to the influence of task with higher irregularity typically, but not exclusively, found in speech, but the present data did not reveal any relationship with age.

The results derived from singing are important. Not only are the values lower across all the age groups, but the average percentage irregularity diminishes as the age increases. (Average values starting at age 8yrs:- 9.9; 5.5; 5.38; 4.4; 3.93; 1.77). The inference that this is the consequence of training is undermined by identification of individual subjects within the age groups who had higher values than the average, (one subject being the head chorister). There are two other pertinent factors; (i) increased motor control related to maturation of the central nervous system, and (ii) improved breath support resulting from development of the respiratory mechanism.

This would be consistent with the typically lower percentage irregularity in reading because of the predisposition to use a more supported voice when reading than in spontaneous speech.

Taking account of all the factors the range of irregularity values is plausible.

Notwithstanding the variability certain trends emerge.

As referred to above, the predominant relationship between the tasks was that the highest CFx irregularity was derived from the speech sample and the lowest from the singing sample; the largest number of subjects demonstrating this trend fell in the 11-year-old group (mean age 11.27years) which may be related to their singing skills combining with increased respiratory support at this age. (Pedersen (1985) suggests singing ability is *"maximal"* at 11.9years).

Inspection of the subject group with the lowest CFx irregularity value in reading (relative to other tasks) demonstrated that the largest number of this group fell in the 10-year age group. This indicates that the 10-year-old subjects are more inclined to have more CFx irregularity in both singing and spontaneous speech. This may be accounted for by a combination of factors. On the one hand improved reading skills enabling them to control breath support and pitch changes, on the other an emerging instability in the laryngeal apparatus affects the regularity of tasks when they are both more relaxed (in spontaneous speech), or are making more demands on the mechanism, (singing).

Very few subjects showed a higher CFx irregularity in singing than in the other tasks, and even fewer showed a lower CFx irregularity in speech than in other tasks.

All these results demonstrate a relationship between CFx regularity and task. Because of the close relationship between mean Fo in reading and spontaneous speech, it is unlikely that this is pitch dependent and points to a relationship between CFx irregularity and breath support.

CFx RELATED TO CQx

Relating the CFx findings to measures of CQx percentage irregularity demonstrated that typically the CQx values derived from reading and speech were relatively higher than those derived from singing. Of those subjects found to have a relatively higher CQx value in singing than in either reading or speech the largest group was the 10-year-old group; whereas the largest group with relatively lower CQx values in singing were 11-years-old. These findings point to an instability in the control of the vocal fold vibratory cycle evident at the age of 10years.

However, these patterns were not absolute and some subjects demonstrate different relative values, (eg the highest CQx in reading).

The relationship between CFx and CQx (ie the values for reading, speech and singing in relation to each other) was the same in a substantial percentage of samples but only one subject showed this pattern in all three sets of recordings.

Relating CFx and CQx values demonstrated that only a few subjects had both higher CFx and CQx values in singing relative to other tasks. Relatively lower CQx values with higher CFx values were found in a small number of subjects in speech but this pattern was not evident at all in singing.

Relating these results to the perceptual evaluation demonstrated that a breathy quality was mostly associated with a CFx value of less than 10%, and a CQx value above 50%.

These findings were supported by observation:-

- As previously reported a number of subjects sang out of tune.
- Diction was frequently characterised by emphatic articulation. Attempts to roll /r/ resulted in increased friction, particularly following a labial plosive, (praise).
- The subjects demonstrated varying degrees of laryngeal movement; typically a relatively stable laryngeal posture was associated with good breath support.
- The perceptual vocal quality is related to breath support. Those subjects who introduced a lot of friction were also noted to be unable to control their breath support as effectively.
- Those subjects who were noted have good breath support in singing also demonstrated lower CQx values; however, comparable values were also found in subjects noted to have a breathy quality precluding any robust conclusion.
- Lower CQx values were found in subjects who experienced reduced pitch control (pitch breaks) when singing.
- Higher CQx values were associated with perceived strain – noted to be secondary to inadequate breath support.
- Subjects with both high CFx and high CQx values were all age 12-12.5years, with the exception of one subject who was showing signs of precocious maturation.

To identify whether these results identified the effect of training the QxFx distributions were inspected. Relating all the findings, the results of the present study did not generate any evidence of the influence of training. This could be inferred if there were evidence that behaviours learning in singing are generalised across other voice use activities, (particularly breath control); however, the relationship between the various measures for reading and speech suggests a dependency primarily on physiological factors; notably increased respiratory support. It would also be expected that training would develop the stability of vocal function and therefore have the effect of decreasing variability.

Are changes in vocal fold vibrational characteristics related to any of the measurements of weight and height?

The purpose of measuring height and weight was primarily to relate growth to published standards to meet the criterion of 'normal'. From this it was logical to relate these measures to Fo measures although no direct relationship was expected, beyond that which resulted from the correlation of maturation and growth and consequent changes in mean Fo.

The height and weight measures for three subjects fell outside the average for their age,(two were very small, and one was very tall), although inspection of the data pointed to increased height associated with the lower Fo there is no evidence that this is independent of maturation. This finding was limited by an insufficient number of subjects of exactly the same age.

Measurement of the vertical laryngeal dimension was productive, demonstrating (a) that there is not direct relationship between this measurement and Fo, but that there is a clear relationship between an increase in this measurement and a lowering of the mean Fo. Because the childs' larynx is so small it requires skill to take this measurement and some of the data had to be discarded because it was obviously unreliable; however this finding does demonstrate that although Fo cannot be predicted, or even calculated from this measurement it could be useful as part of a system to monitoring vocal function.

Can voice change associated with maturation be predicted from certain physical measures?

This question was posed because of the aim to identify whether, by predicting voice change the vocal demands placed upon these young choristers could be appropriately modified to prevent any potentially detrimental effect on the vocal folds. Although there is no evidence that vocal problems subsequently adversely affect vocal function neither is there evidence that it does not and therefore those responsible for the care of these children should be cautious. Clinical experience supports the considered view that children do not 'grow out' of a problem and points to the importance of early intervention when there is any change in vocal function.

This question should in fact be re-worded. Voice change associated with maturation obviously can be predicted because normal maturation is associated with physical and physiological changes which result in a lowering of mean Fo.

If the question becomes can physical measures predict the Fo mean and range they clearly cannot.

If the question becomes can changes in certain physical measurements (excluding clinical testing of levels of testosterone etc and including measures of vocal fold vibratory behaviour) indicate the onset of the process of change the results of this study suggest this is possible by monitoring the rate of growth of the vertical dimension of the larynx, and the application analyses obtained by ELG.

11.2 Limitations and strengths of the Study

The information derived from this research is presented as a contribution to the database on vocal function in children. The results of quantitative analyses and perceptual evaluation are described, supported by biometric information.

In some respects a limitation of this study, that the investigations were not and could not be undertaken under strict laboratory conditions, is the consequence of one of its strengths, which is the relative naturalness of the way in which the investigations were completed. But this also highlights a difficulty of investigating vocal function, particularly in children - that if rigorous criteria are applied to the methodology the resulting voice production may be contrived and not representative of typical voice use.

Equipment

The decision to use ELG followed the choice of the Laryngograph system for use in the clinic, and for the study of normal adult voices previously undertaken. It is suitable for use with children, being non-invasive, and is impervious to extraneous noise. It is widely used in the U.K. enabling cross-referencing of data between studies.

The use of ELG enables analyses of the vocal fold vibratory behaviours which cannot be obtained from an acoustic signal alone.

A limitation of the system can be potential electrode displacement and inflexibility of the electrode placement in relation to laryngeal movement. Assessment including the very high and very low pitches (pitch glides and scales), also have to take account of possible displacement of the electrodes by laryngeal movement. Although Colton and Conture (1990) suggest that either the subject or the researcher may hold the electrodes, attempts to guide the electrodes according to the rising pitch actually either anticipate or follow the acoustic output and the result will not therefore be an accurate reflection of the performance, and for that reason, in this study there was no interference with the electrode placement during a task.

Materials

The subjects of this study were accustomed to performing so were not inhibited about reading aloud and singing. The results of attempts to elicit samples of conversational speech were rather more variable, some subjects being less forthcoming than others. This was considered by this researcher, from anecdotal evidence, to be typical of the communicative behaviours of boys of this age. (Morris (1997) used the 'Cookie Theft' picture, (Goodglass and Kaplan 1983) to elicit connected speech and reported prompting boys who provided less than twenty-five seconds of speech, which suggests that researcher encountered a similar difficulty). Such reticence could possibly be overcome by recording subjects speaking to each other, rather than an individual boy speaking to a researcher.

The full voice range is not revealed by reading, conversation or singing, since in all these instances the subject may restrict the pitch range which he uses, (because of mood, circumstance, difficulty reading or the combined nature of the unnaturalness of material used). Pitch glides may demonstrate the full attainable voice range, but are typically produced in singing rather than speaking mode and as such do not reflect the pitch range capacity of the speaking voice. The subjects in the present study also completed a pitch glide, (low to high; high to low; mid to high; mid to low); however it was found that these subjects could not reliably judge their range resulting in strained phonation at both extremities of the range, or stopping before reaching the highest/lowest pitch. Selection of a part of the sample to exclude these extremities would be based on the perceptual (subjective) judgement of the researcher and therefore arbitrary. (McAllister (2000) comments that *"In comparing voice pitch ranges it seems important to distinguish between the true physiological range and a range consisting only of tones that the subject and /or the experimenter regards as 'acceptable'".*) The subjects also reported that they felt they were judging the pitch glide against the range of scales which they practise and therefore had a perceptual target. To investigate phonational frequency range Hollien et al (1994) presented recorded tones in semitone steps and asked the subjects to phonate at the same frequency, but suggested that the results may have underestimated the pitch range by as much as a semitone.

No measurement or control of vocal intensity was applied. Subjects were asked to perform the vowel tasks at a comfortable pitch and intensity; the intensity of the conversation, reading and singing tasks was self-adjusted.

<u>The Subjects</u>

The inability to control the attendance of subjects resulted in differing intervals between recordings, which ranged from nine months to fourteen months, (average 11.8months). Because the subjects attended according to their school and Cathedral timetables the older boys did not attend towards the end of the school term when they were doing final exams, resulting in a very small number of measurements for boys age thirteen. The distribution of the ages is likewise unbalanced. A conclusion of this study is that an interval of twelve months is too long to provide information on subtle changes occurring at a time of rapid growth.

Indirect Laryngoscopy

Mirror examination was undertaken by a highly experienced E.N.T. consultant specialising in voice and therefore provided adequate information on the condition and mobility of the vocal folds without exposing the subjects to a more protracted and less tolerable procedure, (ie videostroboscopy). Although it is recognised that videostroboscopy provides more detailed information on the vocal fold vibration and mucosal wave, useful for both differential diagnosis and scrutiny of the vocal fold behaviour of the performing voice, Woo et al (1991) comment on its limitation and, as Prytz (1987) points out, the result *"depends upon the physician's clinical skill and ability to observe and describe observations."* (1998) used stroboscopy in a study of the relationship of vocal fold length and voice Fo and reported that *"stroboscopic findings suggest a change in the structure and mass of the vocal folds at this time of maximum frequency change."*; since the technology does not yet enable quantification of the mucosal wave pattern, this finding was based on a subjective judgement leading these researchers to acknowledge that any conclusions drawn were speculative. The difficulty obtaining a good view of the vocal folds of three subjects in this study, because of the shape of the epiglottis, applies equally to any form of indirect laryngoscopy.

Because one specialist undertook all the examinations the reliability of judgements may be challenged; however the purpose of this screening examination was to confirm the health of the vocal folds and exclude any obvious pathology or abnormality of function; the experience of the practitioner was therefore the critical factor. Furthermore, clinically, these aspects do not lend themselves to interpretation but require absolute judgements. The voice recordings provided a sample of an individual's voice at that time. Although it may be argued that those subjects who were found on E.N.T. examination to present with some atypical feature should have been reviewed and recorded when that feature resolved, the intention of the study was to capture a sample of current voice use; none of the subjects were considered by the choirmaster and singing teacher to have any element of vocal dysfunction and were therefore participating fully in all the choral activities. All the E.N.T examinations were undertaken in the presence of the researcher and the findings discussed for agreement on whether or not the subject should be included in the study, (all findings were reported to the school matron and choirmaster; any atypical features were reported to the school doctor).

It was not possible because of ethical constraints, to undertake more detailed clinical studies to identify stages of growth and maturation, (ie. bone x-ray; androgen status).

Perceptual Evaluation

It is evident from reference to other studies of children that perceptual evaluation is not routinely included as a part of the research methodology, and that where it is used it is fairly arbitrary. The perceptual evaluation for the present study was undertaken by the researcher, who, although trained in formal protocols, (Voice Profile Analysis and GRBAS), may stand accused of listener bias. However relevant factors of rater experience, the protocol applied, and the sample size, (Carding et al. 2000) were taken into account, and the use of a formalised evaluation protocol provides a useful reference for other studies. The perceptual evaluation was made from the audio recording, and cross-referenced with notes made at the time of recording. There may be features of the singing voice which are difficult to correlate with physiological or acoustic features which are discernible to the professional singer or teaching of singing , and often explained using imagery, that are not apparent to other voice specialists. The Voice Profile Assessment in Singing (VPASP), based on the VPA and incorporating most of the parameters used in the GRBAS scale (Williams et al 2005), was not available at the time.

Psychological Evaluation

As reported, a condition of the collaboration of the cathedral in this study was that the subjects would not be asked any specific questions regarding their home lives and family background. Subjects who spontaneously talked about their homes and families could be responded to appropriately, as long as the conversation did not encroach on any sensitive issues. This excluded asking any subject how he felt about being a chorister, or being away from home, and similar pertinent issues. Peer group pressure, parental expectations and fear of failure in a high profile environment, with the educational opportunities dependent on the ability to perform in the choir, are significant factors warranting further investigation.

This researcher would argue that when it was advised that a child should rest from singing, the reaction of the individual is determined by the attitude of their mentors and peer group, and that a negative reaction can be avoided when respite from singing is perceived as a normal event.

The subjects of the present study did not present with voice disorders and caution should be exercised in screening which may lead to judgements regarding selection according to personality. However evaluation may provide useful insights to support the care of the choristers.

Responsibility for the welfare of these children extends beyond their abilities to participate in the choral activities, and the psychological effect on a child who has to leave a choir school because of vocal problems, (as occurred with one subject in this study) is unknown; or indeed the impression left on the remaining choristers when one of their midst leaves under such circumstances. Compared to children who train extensively in sports, ballet, music and drama, the boy chorister is unique; he is striving hard to do something which, in the natural course of events, he will have to stop doing in that form. As he reaches the peak of his ability in terms of musical competence, the capacity of the 'instrument' has already started to change. No published studies have investigated the long term effect on the vocal apparatus and the psychological ramifications; both would be extremely difficult because of the numerous other factors which may subsequently affect the voice and how experiences are construed. Anecdotal evidence suggests that there are two schools of thoughts amongst former choristers, one that, "it didn't do me any harm,"; the other, "it ruined my voice", (both quotes from personal communication with this researcher).

The question about the role of children in these professional choirs which this study does not ask, (in the same way that the use of children in industry was first accepted, then taken for granted until finally challenged), is why is this tradition sustained? The introduction of girl choristers into the cathedral choirs has broken a centuries old tradition, opening the door for a more circumspect appraisal of the use of these young children and the demands placed upon them.

Data Analysis

This study has generated a large amount of data relating to quantifiable aspects of vocal function, and biometric measures. Variability and complexity are pervasive and the merits of certain types of statistical analysis (such as factor analysis) when the subject group is small are not obvious. The present descriptive study can perhaps best be considered as essential groundwork for further studies with carefully controlled groups of subjects allowing valid inter-group comparisons, more suitable to statistical treatment. Nevertheless in the ELG analyses presented, data reduction and organisation are achieved by the use of statistical treatments central to the Speech Studio software. These treatments yield the speech and singing values (eg, Fo, irregularity), upon which discussion and conclusions are based.

Whilst this study could be considered to have, inevitably, certain deficiencies in respect of the methodology, the resulting data is deemed valid and to represent a useful early comprehensive contribution to the field.

Developments in technology facilitate the measurement of the acoustic element of the voice and support the diagnosis and remediation of dysphonia. However voice production involves many behaviours which are pertinent to the way the sound is produced but are not reflected in any measurement. Behaviours related to effort or vocal strain, such as clavicular breathing, ingressive gasps, exaggerated jaw movements, are particularly important and are not evident from measurement or auditory perceptual evaluation, but could be identified from video recordings and would provide information not only on what is produced but how, which - from a clinical perspective - is a most important issue.

The results are derived from a range of materials and based on a comprehensive range of investigations. The results demonstrate that ENT examination and audiometric evaluation are fundamental to any study of child voice, especially as clinical experience has shown that people with minor vocal fold pathologies can sustain voicing, essentially 'pushing through' the problem. The results of spirometry not only excluded any significant respiratory disturbance but also identified aspects which invite further investigation. In including evaluation of a number of variables this study has endeavoured to provide holistic profiles of the subjects and to reflect *"functional unity"* by presenting the data in the context of several pertinent aspects of child voice.

Notwithstanding the limitations referred to the strength of this study is that it is based on a range of investigations to provide a comprehensive evaluation of critical aspects (laryngeal health, respiratory health, and hearing), and the results are derived from analyses generated by the Speech Studio system of a range of materials; furthermore all samples were substantial.

11.3 Proposals for future work

As well as answering certain questions, the present study has provoked many more. Although a large amount of data has been analysed and the relationships between different measures explored there is the potential for further evaluation of the data obtained.

- Of particular interest is the changing configuration of the DFx distribution histograms which invites further study of measures of skew and kurtosis.

- The measures of respiratory function, related to the measures of Fo irregularity and contact quotient irregularity, and to perceptual evaluation highlight the importance of this aspect. It is proposed that the existing data is reviewed to identify potential further application; however, the measures of respiratory function did not include assessment of controlled expiration relevant to the co-ordination of expiration and phonation.

- Analyses of the data derived from ELG has been comprehensive in respect of the measures of Fo mean and range, and measures of CFx and CQx percentage irregularity. However features of individual vocal fold behaviours were particularly notable and warrant further inspection.

11.4 Recommendations arising from the study

This study was instigated to identify factors to support and improve the care of choristers in relation to voice use. Definite aspects emerge on which recommendations are based,

- The level of reading and motor speech skills is pertinent since any difficulties with reading and / or articulation can affect voice production. These skills should be assessed to ensure that the singing material introduced is within the choristers level of competence.

- Evaluation of vocal function should be based on the speaking voice because any problems can be disguised by pushing through in the singing voice.

- Routine ENT screening, (including hearing tests) should be provided as an integral part of their vocal welfare.

- Voice assessments to measure mean Fo, Fo range and the characteristics of the irregularity of the vocal fold vibratory cycle should be completed regularly to monitor the capabilities of the laryngeal apparatus.
- Children should sing within their comfortable range, with equal importance given to the low frequencies of the range as to the high frequencies.
- Evidence of insidious instability in the laryngeal apparatus at around age 10years should be responded to with a reduction in the vocal demands placed on them.
- Any change of vocal quality should be followed up to prevent maladaptive compensatory strategies being used.
- Although there may be aspects of vocal function which require evaluation of a larger subject group, cross-referencing is hindered by differences in methodologies; it is evident that the validity of studies of child voice is dependent on inclusion of an ENT examination,

11.5 Conclusions

During the course of the present study it appeared that although there was a wealth of data the number of variables, combined with the inter and intrasubject variability would frustrate the identification of clear conclusions. Taking account of all the factors it is apparent that this is not the case and robust findings have emerged. The aim of the study was to obtain information to support the care of the choristers because of the problems which were being identified through an ENT clinic and therefore had a clinical impetus.

The results of the present work demonstrate that against a background of clinical support, which was not available for choirmasters and teachers of singing to access in the 19^{th} and early 20^{th} century, and the scope for identifying the characteristics of the vocal fold vibratory cycle made possible by advances in ELG the process of change in vocal function not only can but should be routinely and regularly monitored, to appropriately manage the vocal welfare of these children.

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THE TRAINING OF CHORISTERS - A HISTORICAL PERSPECTIVE

Selection of choristers

It is apparent from Curwen's text (1891), that choirmasters in the 19th Century had far more applicants to their choirs than their modern day counterparts, with the decline in church-going resulting in fewer boys singing in their parish church choirs who would develop an interest and aspire to a Cathedral choir. Consequently it is suggested that *"Before commencing to train a voice the choirmaster must make sure that it is a voice worth training."*, and that *"Boys who have fallen into thoroughly bad habits should therefore be dismissed and a fresh selection made."*

Mr. W.H.Richardson, is said to advise; *"Make your choir as large as possible. Take all who will come into it, and do not go through the form of "trying" voices that have never been tried themselves, and of which you can form no opinion. For adults this is a necessity, but for children it is better to get one or two per cent, of naturally defective learners, rather than to turn away all but those showing undoubtedly exceptional ability."* Mr Richardson was choirmaster of the Swanley Orphans' Choir, highly acclaimed for the standard of singing from the children who clearly did not choose to be there.

Social factors

Curwen also discusses social distinctions quoting The Rev. E Husband of Folkestone who considered the *"richer and fuller"* voices of the working class boys better than those of the 'sons of gentlemen'. Whilst attributing this to the *"plain food and outdoor life"* he also explains that the working class children start singing at nursery school at the age of four years, whereas the 'sons of gentlemen' who are brought up with governesses or attend preparatory school often to do not learn to sing at all. Mr T.H. Collinson, Mus.B. Organist of St. Mary's, Edinburgh included as part of the selection process, *"inspection of homes, as to overcrowding, &c."*

Comment is made on *"the special difficulties of agricultural districts."*:- *" the lower register of a country boy is, as a rule, coarse."* Mr W.W.Pearson, Choirmaster, Dereham, Norfolk describes his charges voices as *"for the most part, flabby, wanting in resonance and quality"* suggesting *"This may be the effect of the low elevation above the sea-level, and the damp humid atmosphere; or it may be partly due to race."*(Mr Pearson's emphases).

Perhaps the last word on selection should be that of Dr.Longhurst of Canterbury Cathedral who, it is stated, claimed that *"as a result of forty-eight years' experience, he can tell by the look of a boy whether he will make a chorister. There is something about the brows and eyes, and general contour of the face which guides him. He is never mistaken."*

Two choirmasters consider the boys ability to read as a selection criteria.

Age of choristers

The Rev. W Mann, Precentor of Bristol, advises securing boys between the ages of 9 and 11years. Boys joined Westminster Abbey from age 9 to 10½ years; St.Mary's Edinburgh at 9 -12years with the boys *"worked in divisions to minimise their duties."*; The Temple Church at 8 years (for at least one year as probationers. The age limit is now 7years); Lincoln Cathedral at 8 years with the qualification that *"for two years, although they wear surplices, they do not sing."*; Salisbury Cathedral from 8years to 11 years, but not over 11years; St.Paul's Cathedral at between 8–10years. At Lincolns' Inn Chapter boys *"come with a fair knowledge of music at about 9 years of age"* and at Canterbury the boys were the youngest reported, at as soon after 7 years as possible.

The Art of Managing Choir Boys

M Sergison, Organist of St.Peters'. Eaton Square, London advises that the choirmaster, *"should enter into the boy's way of looking at things, and remember that they have deep feelings."*. Comments from other choirmasters emphasise the balance of discipline and fairness, *"never over-praise clever boys; never snub dull ones"*; encouraging the boys to take responsibility, and preventing jealousy and conceit.

Comment on the choirmaster comes from a cathedral precentor who is quoted as saying *"A cathedral organist is specially exposed to the temptation to hastiness and harshness, owing to the power he possesses. A parent values the position of a chorister for his son, and the organist is tempted soon to take advantage of the parent's unwillingness to withdraw his son,... I fear there is a vulgar notion (only half-defined, most probably) that irascibility in the musical trainer is a mark of genius."*

The impression given by Curwen is that he considers that discipline should be tempered by sensitivity with the advice that reproof should be given in private. Today the website of a famous Church choir explains the arrangement for payment to choristers singing at weddings and that *"The Director of Music's word on these payments is final, and he has the authority to stop payment to any boy who he believes has behaved badly."*

The Management of Breath

Curwen explains that there are three methods of breathing; (i) involving lowering the diaphragm, (ii) involving extending the ribs, and (iii) drawing up the collar bone and shoulder blades – which the reader is told is bad. It is suggested that choir practice should begin with a few minutes devoted to breathing exercises.

Posture

"Rigidity is the enemy of all good singing."

The advice on posture is consistent, with the importance of the muscles of the head, neck and throat being relaxed. The boys should not stoop, so music books should be placed on a shelf to prevent this. They should hold their heads up, to allow the voice to carry further. Standing they should be *"upright and free"*, when sitting an *"upright posture hinders the breath less than lolling and a crooked posture"*.

Pronunciation in Singing

Reference is made to the problem caused because the choristers of Lincoln Cathedral attend day school with boys who speak with a Lincolnshire dialect. It is suggested that in singing they should use the tongue, using the lips as little as possible. Mr W H Richardson advises to *"Guard against giving prominence to consonants. "Rolling "r's" is very well, but to precede the vowel with a sound not unlike the noise caused by springing a police rattle is neither artistic nor pleasing."* Another choirmaster advises practising vowels, in piano and staccato as preceding consonants *"disguise a wrong action of the glottis, without removing the fault."* and suggests that *"E" has the advantage of bringing the vocal cords very close together, thereby effecting a greater economy of the breath than is possible with the other vowels."*. Exercises sung to *"koo"* are recommended to throw the tone forward. Curwen advocates using the Tonic Sol-fa notation system, teaching the boys to sing by ear and by note.

Tone

The recurring themes of the various choirmasters are:- that there should be no effort; scales and exercises, especially the top notes, should be sung softly; and scales should be practised descending to train the boys through the break in voice so that it becomes imperceptible, although the Precentor of Bristol, whilst also supporting singing quietly suggests gliding the chest voice into the upper register. The organist of Lincoln Cathedral (Mr J.M.W.Young Esq.) advises that *"...care should be taken that the trebles are never allowed to sing even the middle notes loud, only mf, and they should be frequently practised to sing piano.*(Mr.Young's emphases). McKenzie (1956) similarly emphasises the importance of singing softly, and comments on the relationship between the use of the speaking voice, particularly that boys will be inclined to shout as they find their voices becoming more powerful.

Voice Breaks

The most appropriate comment on voice breaks is that made by McKenzie (1956):- *"a boy's voice never breaks.* (authors emphasis) *Physiologically, the vocal chords lengthen at an age varying with individuals, and the voice in consequence changes. Nothing in the vocal apparatus breaks or does anything that could reasonably be described by that word."*

The issues around the maturing voice are no different from those being discussed today. Curwen states at the beginning of the book (First Edition, 1891) that *"There is no doubt that it is undesirable for a boy to continue to sing after his voice has shown signs of "breaking".* In the Fourth Edition (1900) he concludes that *"the preponderance of evidence is in favour of rest."* (ie of the developing voice.) McKenzie (1956) refers to the view of early authorities (Behnke and Browne, 1885) that *"the bulk of the evidence most strikingly proves the injurious and even ruinous consequences arising from the exercise of the voice by singing during the period of change.",* although they subsequently suggested that where voice change was gradual, with no 'break' singing *"may possibly"* continue under guidance.

Curwen describes signs of change as *"the middle register becoming weak without diminution of power and quality of upper notes";* the *"thick register"* becomes stronger; the ability to strike middle C with firmness, which according to Mr G Bernard Gilbert *"is usually sufficient to decide the point."*, also commenting that it becomes husky and *"of uncertain intonation."*. Mr Fred Cambridge of Croydon Parish Church considers that *"as soon as a boy's voice reaches only Eb, it is quite time he left off singing altogether."*

Mr R H Saxton, Choirmaster of St. James's Church, Buxton advises that this aspect is determined according to the circumstances of each individual and in a subsequent discussion of alto boys it is pointed out that the pitch of the speaking voice is affected by height and size and that there is no physiological basis for assuming every boy is a treble.

McKenzie (1956) suggests that if boys continue to sing when the higher range is changing, it also affects the lower notes, which he describes as the bottom of the voice 'dropping out' compromising the development of the lower range of the voice.

McKenzie focuses on the way in which the voice is used and transition from soprano to tenor /bass using what is referred to as the Alto-Tenor Plan; however the emphasis is placed on the boys using their voices properly without forcing.

Vocal Registers

Curwen explains that the terms used – thick, thin, small, describe the physiological action. In the 'thick' register, the whole thickness of the vocal cords is used; in the 'thin' register, the thin edges alone are used, and in the 'small' register, there is a small aperture.

The range of registers is as shown below and is also related to the terms chest, middle and falsetto. The choirmaster of Liverpool Cathedral explains that *"As a boy gets older he uses the upper register much lower down."*

Background to the Choir School in relation to the study

The Cathedral has had a choir school for over 800 years. At the time of this study the school had 40 boys from the ages of 8–13 years who combined the strenuous and demanding life of a chorister with an exacting academic curriculum which included learning at least one musical instrument. In 1984 a Choir School Foundation was established at the Cathedral to award bursaries to choristers who could not otherwise attend because of the lack of means, thereby attracting pupils from diverse socio-economic backgrounds.

The boys form the treble line of the Cathedral Choir and in addition to singing the daily office and Sunday Services, they sing at special services for State and important occasions, tour abroad to perform, and undertake recording engagements. Places at the Choir School are prestigious and often sons follow fathers, and brothers follow brothers. The Cathedral aims to balance the welfare of the boys with the requirements to achieve the expected level of performance; they are regarded as professional performers.

How to address vocal dysfunction was a contentious issue. Most of the boys enjoyed, and derived much satisfaction from singing. The school considered exclusion from the choir, for even a short period, for whatever reason, psychologically detrimental. Recommendations from the clinicians involved, that a child should not be singing, could not, unless there was pathological change to the vocal folds, be supported by evidence that continued singing would have an adverse effect on the laryngeal apparatus. There is no known published data to show whether transient vocal abuse in childhood affects the vocal fold tissue in the long term; however, the clinicians involved did not support the view that a chorister with vocal problems should continue to sing on the basis that *"his vocal problems will resolve themselves once he has moved on to his next school"*, (personal communication from a singing teacher to this researcher).

The Choir School specified that no questions should be put to any chorister about personal /family matters or anything relating to emotions for the purpose of the study. The reason given was that as the boys were boarders, and some were experiencing personal and family difficulties at the time, questions about home life etc. may have caused distress.

The boys were given the questionnaire to complete when they first arrived in the Speech Therapy clinic. It was emphasised that (i) although the questions did not require any information which might be considered confidential, no information would be divulged to any other third party; (ii) if they had difficulty reading any of the questionnaire, or had any queries, they could ask the researcher, (iii) it did not matter if they did not want to answer, or did not know how to answer any question.

The Research Protocol

Please read the notes attached to this form before preparing your submission.
The form must be completed fully and all necessary signatures obtained.

DISTRICT RESEARCH ETHICS COMMITTEE
City and Hackney District Health Authority

APPLICATION FOR ETHICAL APPROVAL

1 Title of Study: A QUANTITATIVE ASSESSMENT OF THE VOCAL FUNCTION OF MALE CHORISTERS AGED 7 - 13 YEARS

2. Consultant(s) in Charge of Study: MR M KEENE

3. a) Investigator(s): DAPHNE PEARCE
b) Contact Name and tel.no. in the event of queries: SBH 071 601 7168

4. Where will the Study be undertaken: ST BARTHOLOMEW'S HOSPITAL

5. Signature(s) of Collaborators in the Study:
(See attached notes)

6. a) Does the Study involve adult patients? ~~YES~~/NO **
b) May the patients be children? YES/~~NO~~ **
(If so, please complete Child Patient Consent Forms)

7. a) Does the Study involve normal volunteers? YES/~~NO~~ **
b) Payment to be made: £

8. If the Study involves normal volunteers, will they be Bart's Medical Students? ~~YES~~/NO/~~NOT KNOWN~~ **

9. If the Study involves the use of any Drugs, please indicate their Licence Status with The Committee on Safety of Medicine:
** (a) Freely available.
** (b) A Clinical Trial Certificate (CTC) has been issued (Please Attach Copy). NOT APPLICABLE
** (c) Exemption from requirement for Clinical Trial Certificate has been granted (Please attach a copy of the letter from DHSS).
** (d) Application for exemption from requirement for CTC has been made.
** (e) Healthy volunteer study - no application to CSM being made.

10. (a) Will the investigator(s) receive any personal fee in respect of this study? ~~YES~~/NO **

(b) Has the Department of the investigator(s) received any financial contribution from a commercial concern connected with the proposed study, within the last 2 years, or will it in the foreseeable future? ~~YES~~/NO **

(c) Has the principal investigator, or any member of his/her department acted as a paid advisor or consultant to a commercial concern connected with the proposed study? ~~YES~~/NO **
(If YES, please attach details as specified in the attached guidelines)

** Delete as applicable.

I CONFIRM THAT I HAVE READ AND APPROVED THE ATTACHED PROTOCOL

Signature of Consultant in Charge............................

Date......30/5/91......

25 copies of this form, when completed, should be accompanied by 25 copies of a detailed protocol(guidelines for protocol enclosed) and the appropriate consent form(s) and returned to the Secretary of the District Research Ethics Committee, West Smithfield Gatehouse, St. Bartholomew's Hospital.
25 COPIES OF THE ENTIRE APPLICATION MUST BE SUBMITTED.

The Committee meets on the third Friday of each month (except August) and items for the agenda should be submitted by the 1st of the month in which you wish the project to be considered. Late applications will not normally be accepted.

A QUANTITATIVE ASSESSMENT OF THE VOCAL FUNCTION OF MALE CHORISTERS AGED 7 – 13 YEARS

The purpose of this study is to identify parameters of voice fundamental frequency range and regularity in male choristers aged 7 -13 years to obtain baseline normative data to assist in the assessment of young males presenting to the clinic with voice disorders.

The subjects will be asked to undergo an ENT examination, a hearing test, measurements of lung function and measurements of growth. On the basis of this data participants conforming to published norms will then be assessed for voice production. This will involve recordings of a range

WHAT ETHICAL ISSUES DOES THE STUDY RAISE?

1 ENT examination by nasendoscopy if no view of the larynx is achieved with indirect laryngoscopy (IDL). Nasendoscopy will involve the use of a 4% Xylocaine spray, provided routinely to the ENT clinic by the pharmacy at St.Bartholomew's Hospital.

2 The Laryngograph is a standard clinical tool, used widely internationally. It conforms to British Standard BS 5724, a recognised standard for electro-medical equipment.

3 If any subject is found to have a previously undiagnosed disorder the school matron and Doctor will be informed by letter.

BACKGROUND TO THE STUDY

Most studies of this subject have been from a musical standpoint. To date only four have attempted to quantify fundamental frequency changes. None has used the electrolaryngograph.
Weiss (1950) provides a comprehensive historical survey which also poses many questions.
Von J Naidr, M Zooril und K Sevcik(1965 Die Pubertalen Veranderungen der Stimme bei Jungen im Verlauf von 5 Jahren) observed 100 boys between 12-15years. The data and subsequent conclusions are useful in broad terms but limited by the relatively high lower age.
O.Tosi, D Postan and C Bianculli (1976 Longitudinal Study of Childrens' Voices at Puberty) studied 33 subjects aged 9.2 -18.1years. The subjects were classified according to the criterion of Tanner (1962) and voice recordings taken at intervals of 4.5months. Data was obtained on glottal frequency and perceptual change of fundamental frequency. The amount of material recorded for analysis was limited (5 sustained vowels and a short sentence) and the subjects did not have an ENT examination to exclude laryngeal pathology. The study was also confined to a particular racial/social group.

Veil Vuorenkoski, Hanna Liisa Lenko, Per Tjernlund, Liisa Vuorenkoski and Jaakko Perheentupa (1978 Fundamental Voice Frequency during normal and abnormal growth and after androgen treatment) assessed 374 subjects aged 6-40years. Material recorded via a contact microphone consisted of a long vowel and standard sentence. As with the Tosi, Postan and Bianculli paper, there was no sung material.

Finally, M.F.Pedersen, S Moller, S Krabbe, E Munk and P Bennett (1985 A Multivariate statistical analysis of voice phenomena related to puberty in Choir Boys) studied the relationship of voice and growth in 48 boys aged 9 -19years. The subjects underwent stroboscopic examination, electroglottography and hormonal investigations. The authors recommend further investigation of children in pubertal groups 2-4 and study of the relationship between fundamental frequency in speech and the highest tones in the phonetogram. This study likewise did not include sung material.
None of the above studies reported on variables which may be significant. It is therefore thought that although the planned study will be a small one and limited to a specific group, by encompassing all aspects of voice it will provide useful data. It will control for major variables and the protocol is applicable to other groups. It is specifically intended to obtain data which will be useful clinically in the treatment of boys developing vocal pathology presenting for treatment in the ENT clinic at St.Bartholomew's Hospital and the possible prevention of voice problems by identifying indices of voice change which may lead to the cessation of choir activities.

PLAN OF THE INVESTIGATION

This study will be undertaken by the Speech Therapy Department at St.Bartholomew's Hospital in collaboration with the Departments of Respiratory Medicine, Child Health, ENT and the Choir School of St.Paul's Cathedral.

All assessments will be undertaken on site at St.Bartholomew's Hospital. Personal information will be recorded on site or in the Choir School and will comply with the requirements of the Data Protection Act.

All choristers between the ages of 7 and 13 years who are willing and available to participate will be include, (maximum total 42). An explanation will be given to each subject and sent to their parent/guardian for approval.

1.1 Subjects

The subjects who will all be male choristers at the Choir School of St.Paul's Cathedral will be grouped according to chronological age in years and months. Subjects should meet the following criteria:-

a) No history of vocal pathology that has prompted referral to a Consultant ENT Surgeon or Speech Therapist, or voice problems resulting from upper respiratory tract infections that required antibiotic treatment by a G.P.

b) No voice problem at present (in the opinion of the subject, Choir Master, ENT Consultant or Speech Therapist undertaking the study).

c) No significant hearing impairment (hearing within normal limits according to the ANSI/ISO (1969) standard. Determined by audiometric screening.

d) Able to perform the materials fluently.

e) No underlying medical condition that might have an effect on voice production.

f) Native speakers of English (a note will be made of any subject who is bilingual)

g) Able to tolerate indirect laryngoscopy or nasendoscopy.

1.2 BACKGROUND INFORMATION REQUIRED.

Subjects will be asked to complete a brief questionnaire; where necessary questions to elicit details about relevant variables will be asked verbally.
The following information will be obtained:-

a) Any relevant medical history
b) Present health, specifically respiratory or allergy related problems.
c) State of dentition and jaw posture (a note will be made of teeth grinding which may indicate excessive jaw tension).
d) Any medication (present or recent past).
e) Dietary factors which may be relevant to vocal function.
f) Amount and circumstances of voice use and type of voice use.
g) Extent and type of vocal training and role in choir.
h) Instruments played.
i) Regional accent and influences on accent.

1.3 PHYSICAL MEASURES OF GROWTH
Measurements will be made under the supervision of Dr.M.Savage, Consultant in Paediatric Endocrinology, SBH, to ensure standardisation of procedure.

a) Height and sitting height
b) Weight
c) Foot length
d) Neck measurements: width and length/laryngeal measurements (using Vernier's callipers).
e) Chest measurements: using standard anthropometric techniques.

This information will embrace all variables affecting the larynx or laryngeal function and ensure that the study is reliable and replicable.

2.1. THE EXPERIMENTAL DESIGN

Each subject will be given a visual examination of ears, nose and throat by a qualified ENT specialist at St.Bartholomew's Hospital immediately prior to the recordings of voice. The criteria for exclusion will be any evidence of vocal pathology at the time. The larynx will be examined by indirect laryngoscopy, however if no adequate view of the vocal folds can be obtained nasendoscopy with lignocaine spray will be used. This is standard practice in the Out-patient clinic. The use of lignocaine and time of administration will be noted as a possible relevant variable; the time of recording will be delayed by one and half hours to ensure no effect remains. Subjects who are unwilling or unable to tolerate nasendoscopy and therefore have not had an adequate examination of their larynx will be excluded. The ears will be examined by otoscope to visually assess for the presence of ear infection; the nose will be examined to check for airway obstruction or other disorder.

2.2 HEARING ASSESSMENT

Hearing assessment –Hearing thresholds will be deteremined with a calibrated, standard audiometer, giving pure tone audiometric assessment of air and bone conduction pathways.

2.3 LUNG FUNCTION

Lung Function. This will be assess with a P.K.Morgan Spiroflow Spirometer linked to computer based pulmonary function analysis software.

2.4 VOICE ASSESSMENT

Recordings will be made on site in the Speech Therapy Department at SBH. If possible they will be made at approximately the same time of day to account for factors such as vocal fatigue and as far as possible provide comparable circumstances for each subject. Recordings will not be made within two hours of a performance or choir practice. The study requires samples of reading, which is therefore repeatable, free speech, providing a sample of spontaneous voice use and song to provide comparison of voice use. Collection of this broad range of material will enable further future analysis.

Spoken Material

a) Reading of standard passages
b) Conversation elicited by standard questions
c) Repetition of a series of sustained vowels.

Sung Material

To include maximum realistic pitch range and sustained phonation. This will be specified and rehearsed.

a) Hymn: 'Praise my Soul, the King of Heaven.'
b) Two octave scale from C to C
c) Two octave argpeggio from C to C

The material will be recorded on a Sony Digital Audio Tape (DAT) recorder using a high quality microphone. The speech signal will be recorded on one channel and the Laryngograph signal will be recorded simultaneously on the other channel. This will provide high quality error free reproduction.

The recorded data will be analysed using available software to provide information about voice fundamental frequency range, mode and regularity and how these parameters correlate with chronological age and physical growth parameters. This information will highlight the relationshop between vocal function and normal development.

All examinations/assessments will be done in the same sequence. If any subject presents with a voice problem at the time of assessment the school Matron/Doctor/parent will be notified as appropriate and therapy offered. They would then be eligible for assessment when the problem has resolved. No subject will be included whilst having any medical condition which may be affecting voice production.

3.1. INVOLVED IN THE STUDY

ST. BARTHOLOMEW'S HOSPITAL

Principal Speech Therapist	Daphne Pearce
ENT Department (including Audiology Dept).	Consultant: Mr M Keene
Department of Child Health.	Consultant Dr M Savage
Department of Respiratory Medicine	Consultant Dr R Davies

CHOIR SCHOOL OF ST. PAUL'S CATHEDRAL

Headmaster	Rev G. Hopley
Organist and Director of Music	Mr J Scott
Matron	Miss J Ross
G.P. to the School	Dr G Neaman

3.2 DATA PROTECTION

All data collection and storage will comply with the district data protection policy.

4 REFERENCES

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(1978) Fundamental Voice Frequency during normal and abnormal growth and after androgen treatment. Arch-Dis-Chil. 53.
PEDERSEN M.F., MOLLET S, KRABBE S, MUNK E, BENNETT P.
(1985) A Multivariate statistical analysis of voice phenomena related to puberty in choir boys. Folia-Phoniatrica

CHILD PATIENT CONSENT FORM (for children under 12 years of age).

Consultant ......MR MR KEENE.............................**Investigator**...........DAPHNE PEARCE....

Purpose of the study and brief description of procedure to be carried out

The purpose of this study is to obtain information about the way boys' voices change as they Grow. This information will be useful when working with boys who are having problems with their voices.

When you come to the clinic you will have your hearing checked and your ears, nose and throat looked at by the ENT Specialist. You will be asked to blow into a lung function machine and you will be weighed and measured. You will also be asked to fill in a short questionnaire.

The voice recording equipment consists of a Digital tape recorder and a laryngograph. This equipment has two small gold plated discs which are placed against your neck and which pick up information about the movements of your vocal cords. You will be asked to do some reading and singing and have a short talk with the person doing the recordings.

When the recordings have been completed they will be run through a computer for analysis and to provide information about your voice.

This study has been explained to me and I understand:

(a) What the study involves.
(b) That refusal to participate will not affect my child's treatment in any way.
(c) That my child may withdraw at any time.

I therefore agree to take part in this study.

Signature of Patient's Parent (s)..Date ....

**

I HAVE BEEN PRESENT WHILE THE PROCEDURE HAS BEEN EXPLAINED TO THE PATIENT'S PARENT AND I HAVE WITNESSED HIS / HER CONSENT FOR HIS/ HER CHILD TO TAKE PART IN IT.

Signature of Witness ....Date.........................
(The Witness should be a person <u>not</u> connected with the study)

Full name and address of patient ....
....
....

** Included for children of 12 years of age or over:-

I HAVE HAD THE STUDY EXPLAINED TO ME AND I AGREE TO TAKE PART IN IT
Signature of patient ....Date.........................

APPENDIX 3(i)

ENT RECORD FORM

SUBJECT NO..............

Part B – to be filled in by ENT Specialist

Has the subject completed the questionnaire in sufficient detail?

YES NO

EXAMINATION

Nose: Ears: Right

Left:

Oropharynx: Nasopharynx:

Larynx / Vocal Folds:

Laryngeal Measurement:

Was the view of the larynx you obtained: GOOD POOR

Did the subject have lignocaine? YES NO

If yes, at what time was it administered: ………………………………………..

Please add any relevant comments: ………………………………………..
………………………………………………………………………………………………………
………………………………………………………………………………………………………
……………………………………………………………………………………………………….

GROWTH AND DEVELOPMENT RECORD FORM

...owth and Development Record
...oys: Birth-19 year...
...eight and Weight
...NNER-WHITEHOUSE (1975)
...f. 11A INTEGRATED SERIES

Hospital/Clinic Name

cm 190 180 170 160 150 140 130 120 110 90 80 70 60 50

Date of Examination	26/11/92	9/12 93	23/2/95								
Age	8.24	9.28	10.48								
Height cm/in	134.0	140.1	146.8								
Height Percentile											
Height Velocity cm/yr		5.9	5.5								
Weight kg/lb	29.4	32.0	37.4								
Weight Percentile											
Weight Velocity kg/yr											
Weight-for-Height Percentile											
Head Circumference cm/in											
Head Circumference Percentile											
Bone Maturity Score											
~~Skeletal Age~~ Chest (cm)	62.1	65.2	68.5								
Puberty Ratings: Genitalia											
Puberty Ratings: Pubic Hair											
Puberty Ratings: Axillary Hair	0	0	0								
Sitting height	72.8	76.3	78.1								
Left Foot	21.1	21.5	23.4								

TABLE OF DECIMALS OF YEAR

	1 JAN.	2 FEB.	3 MAR.	4 APR.	5 MAY	6 JUNE	7 JULY	8 AUG.	9 SEPT.	10 OCT.	11 NOV.	12 DEC.
1	000	085	162	247	329	414	496	581	666	748	833	915
2	003	088	164	249	332	416	499	584	668	751	836	918
3	005	090	167	252	334	419	501	586	671	753	838	921
4	008	093	170	255	337	422	504	589	674	756	841	923
5	011	096	173	258	340	425	507	592	677	759	844	926
6	014	099	175	260	342	427	510	595	679	762	847	929
7	016	101	178	263	345	430	512	597	682	764	849	932
8	019	104	181	266	348	433	515	600	685	767	852	934
9	022	107	184	268	351	436	518	603	688	770	855	937
10	025	110	186	271	353	438	521	605	690	773	858	940
11	027	112	189	274	356	441	523	608	693	775	860	942
12	030	115	192	277	359	444	526	611	696	778	863	945
13	033	118	195	279	362	447	529	614	699	781	866	948
14	036	121	197	282	364	449	532	616	701	784	868	951
15	038	123	200	285	367	452	534	619	704	786	871	953
16	041	126	203	288	370	455	537	622	707	789	874	956
17	044	129	205	290	373	458	540	625	710	792	877	959
18	047	132	208	293	375	460	542	627	712	795	879	962
19	049	134	211	296	378	463	545	630	715	797	882	964
20	052	137	214	299	381	466	548	633	718	800	885	967
21	055	140	216	301	384	468	551	636	721	803	888	970
22	058	142	219	304	386	471	553	638	723	805	890	973
23	060	145	222	307	389	474	556	641	726	808	893	975
24	063	148	225	310	392	477	559	644	729	811	896	978
25	066	151	227	312	395	479	562	647	731	814	899	981
26	068	153	230	315	397	482	564	649	734	816	901	984
27	071	156	233	318	400	485	567	652	737	819	904	986
28	074	159	236	321	403	488	570	655	740	822	907	989
29	077		238	323	405	490	573	658	742	825	910	992
30	079		241	326	408	493	575	660	745	827	912	995
31	082		244		411		578	663		830		997

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Printed in England by Fullpoint Press

RECORD FORM (WEIGHT)

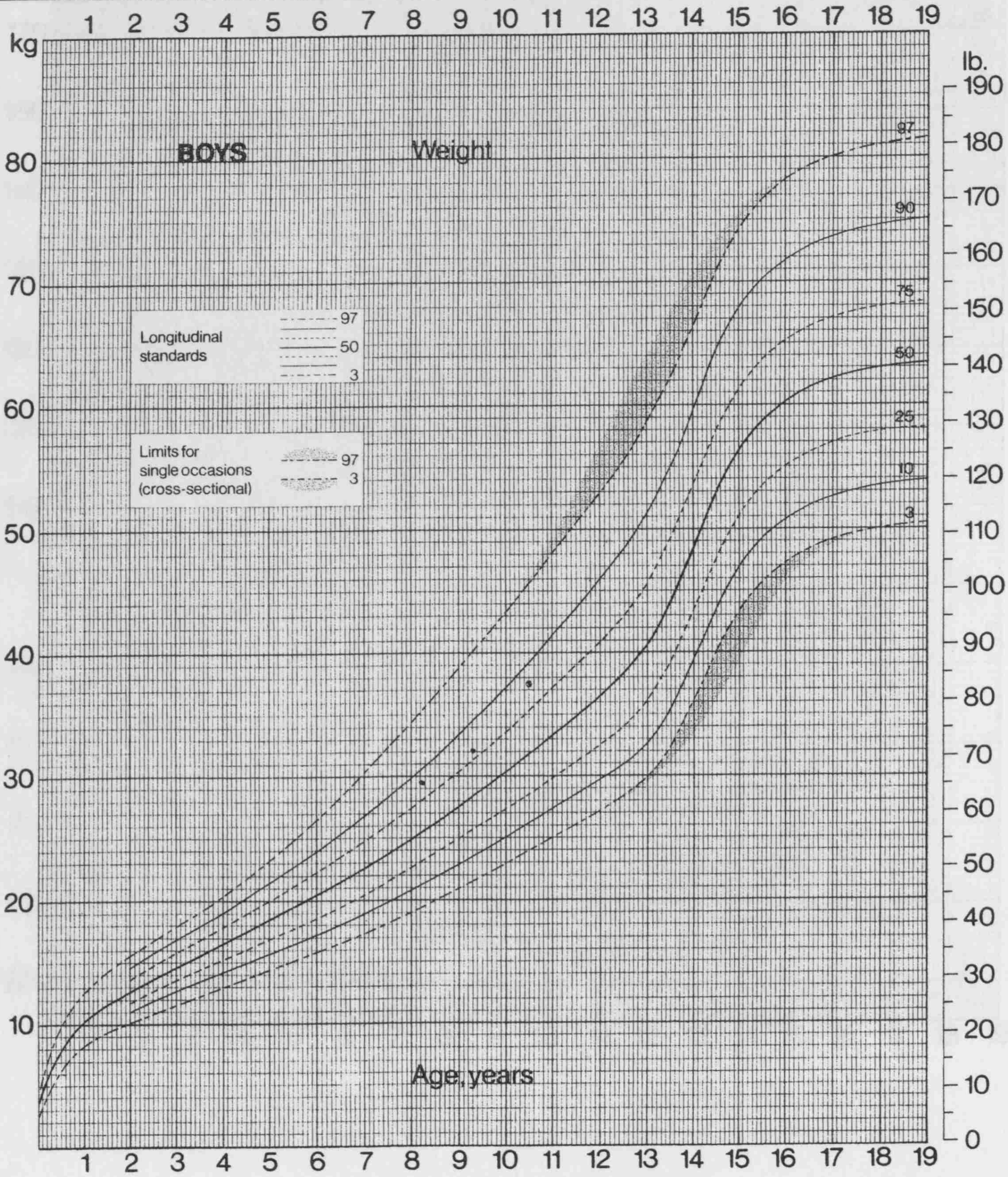
Reg. No.

Surname

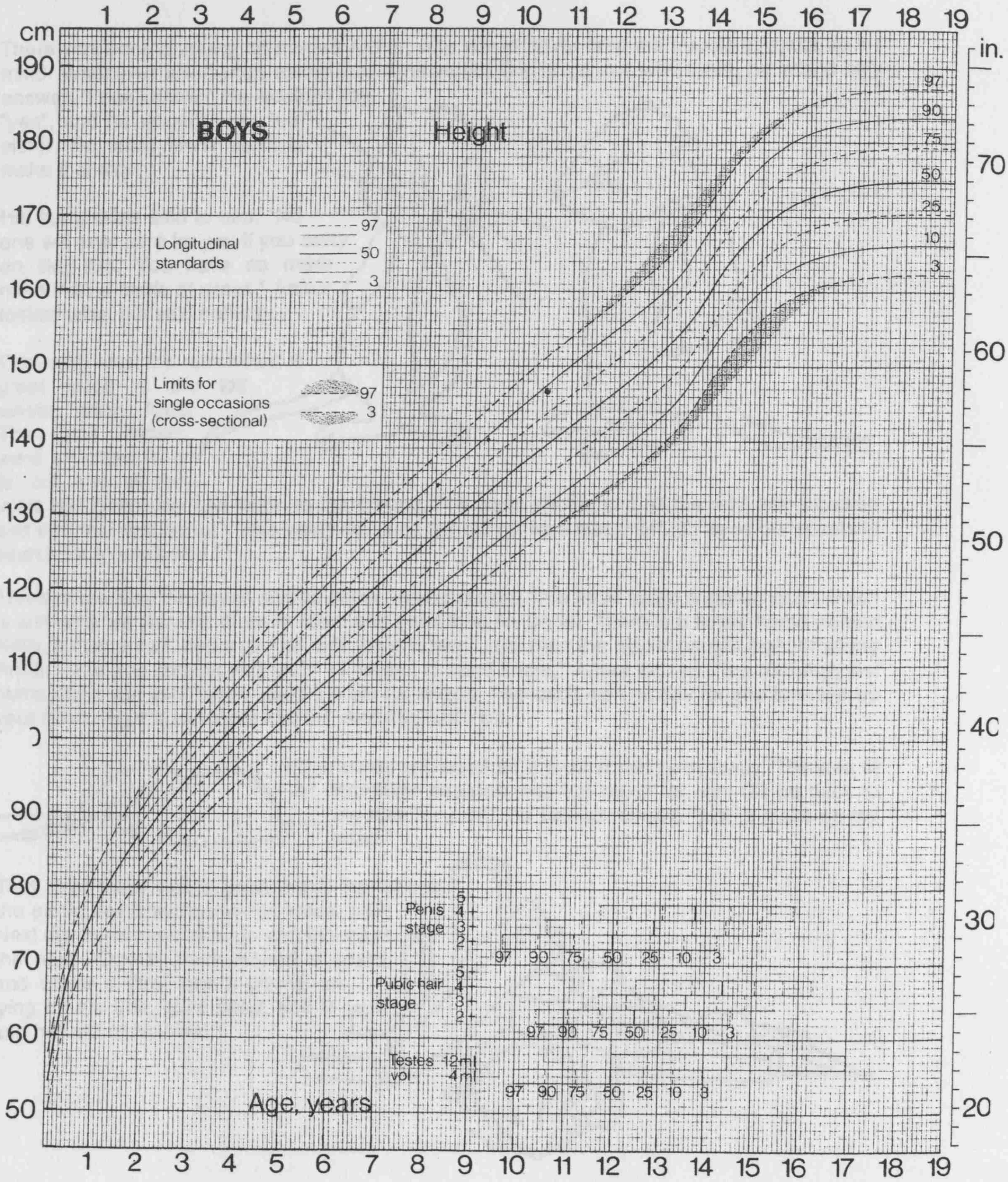
Forename

Date of Birth / / . Decimal Yr.

Notes/Treatment



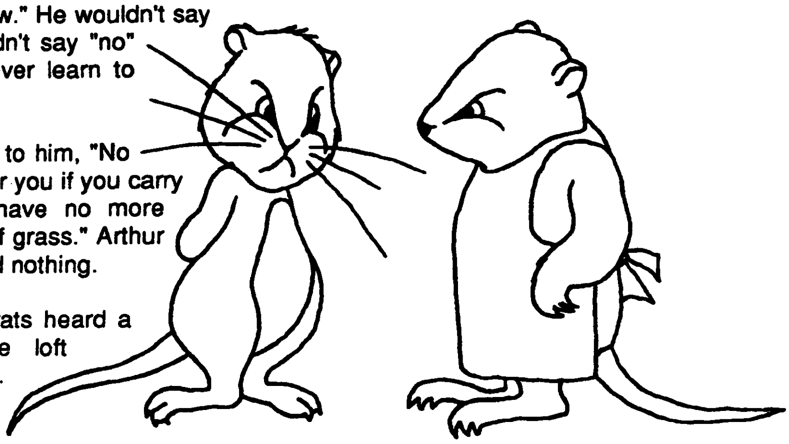
RECORD FORM (HEIGHT)



READING PASSAGE

ARTHUR THE RAT

There was once a young rat named Arthur, who would never take the trouble to make up his mind. Whenever his friends asked him if he would like to go out with them, he would only answer, "I don't know." He wouldn't say "yes", and he wouldn't say "no" either. He could never learn to make a choice.



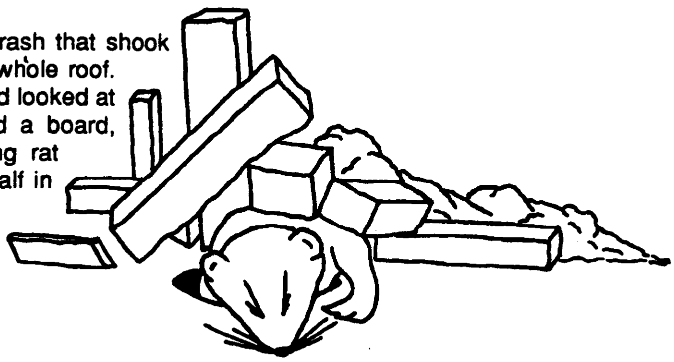
His aunt Helen said to him, "No one will ever care for you if you carry on like this. You have no more mind than a blade of grass." Arthur looked wise, but said nothing.

One rainy day the rats heard a great noise in the loft where they lived. The pine rafters were all rotten, and at last one of the joists had given way and fallen to the ground. The walls shook, and all the rats' hair stood on end with fear and horror. "This won't do," said the old rat who was chief. "I'll send out scouts to search for a new home."

Three hours later the seven scouts came back and said, "We have found a stone house which is just what we wanted: there is room and good food for us all. There is a kindly horse named Nelly, a cow, a calf, and a garden with an elm tree." Just then the old rat caught sight of young Arthur. "Are you coming with us?" he asked. "I don't know," Arthur sighed, "the roof may not come down just yet." "Well," said the old rat angrily, "we can't wait all day for you to make up your mind. Right about face! March!" And they went off.

Arthur stood and watched the other rats hurry away. The idea of an immediate decision was too much for him. "I'll go back to my hole for a bit," he said to himself, "just to make up my mind."

That night there was a great crash that shook the earth, and down came the whole roof. Next day some men rode up and looked at the ruins. One of them moved a board, and under it they saw a young rat lying on his side, quite dead, half in and half out of his hole.



SUBJECT AGE AND INTERVALS BETWEEN TESTS

Subj. No	Age (Years)	Age Interval Year 1 -2	Age Interval Year 2 -3	Subj. No	Age (Years)	Age Interval Year 1 -2	Age Interval Year 2 -3
8	11.29			27	9.79		
	12.28	0.99			10.81	1.02	
	13.28		1		11.83		1.02
11	11.89			28	10.01		
	12.85	0.96			11.12	1.11	
12	10.83				12.03		0.91
	11.81	0.98		29	9.12		
	12.87		1.06		10.22	1.1	
14	12.02				11.22		1
	12.91	0.89		30	9.79		
15	10.29				10.96	1.17	
	11.15	0.86			11.82		0.86
	12.14		0.99	31	8.88		
16	11				9.97	1.09	
	11.9	0.9			10.97		1
	12.89		0.99	32	9.39		
17	11.49				10.48	1.09	
	12.67	1.18			11.48		1
	13.42		0.75	33	8.32		
18	11.99				9.3	0.98	
	13.16	1.17			10.30		1
19	9.17			34	8.65		
	10.2	1.03			9.73	1.08	
	11.15		0.95		10.73		1
20	9.60			35	8.1		
	10.64	1.04			8.98	0.88	
	11.58		0.94		10.02		1.04
21	10.29			36	9.38		
	11.34	1.05			10.39	1.01	
	12.29		0.95		11.41		1.02
22	10.24			37	8.75		
	11.3	1.06			9.8	1.05	
	12.27		0.97		10.68		0.88
23	8.40			38	8.47		
	9.49	1.06			9.48	1.01	
	10.40		0.91		10.48		1
24	9.46			39	8.24		
	10.54	1.08			9.28	1.04	
	11.42		0.88		10.48		
25	9.14			40	8.01		
	10.12	0.98			8.99	0.98	
	11.02		0.9		9.97		1
26	9.78						
	10.77	0.99					
	11.69		0.92				

RESEARCH QUESTIONNAIRE AND SUMMARY OF RESPONSES

Q1. **To ascertain accent / regional features.**

Welsh	2 subjects	Both having Welsh accents
From Dorset	1 subject	No regional accent noted
From Manchester	1 subject	No regional accent noted
From Australia	1 subject	Very slight trace of accent to the attentive listener.

Q2 (a) **Do you get colds (how often)?**

21 subjects reported that they frequently had colds. A further five reported that they were always having a cold, with one describing 'lots of chest infections'. The remaining subjects (14) reported seasonal colds, but did not consider themselves particularly prone to getting a cold.

(b) **Do you get a blocked –up nose.?**

No	5 subjects
Yes but not bothered by it:	8 subjects
Yes, aware of it.	4 subjects
Yes, troubled by it	23 subjects

(c) **Do you get earache? Have you had any ear infections?**

No. of subjects experiencing intermittent earache	6
No. of subjects reporting a history of ear infections.	11
No.of subjects who did not have any ear trouble	22

1 subject reported ringing in his ears.

(d) **Do you have a dry mouth when you wake up.?**

Yes 27 subjects (this includes 2 who reported always waking up with a sore throat.)

No 13 subjects

(e) **Do you usually breathe through your nose or mouth.?**

Mouth breathing only	11 subjects
Nose breathing	12 subjects
Either or both	10 subjects
Not known	7 subjects

(f) Are you taking any medication? (if so what)

Medication for asthma 7 subjects

(g) Have you had any operations (if so what and when)

Subjects were aware of operations they had had but were vague about the timing.

Eye operation	1
Tonsillectomy	1
Appendicectomy	1

Broken limbs were reported:

Broken arm	3 subjects
Broken arm and leg.	1 subject
Broken ankle	1 subject

Q3 To identify TMJ tension.

(a) Do you every clench your jaw?

Yes 14 subjects: No 23 subjects

(b) Do you every grind your teeth?

Yes 13 subjects:

(c) Are your side teeth touching when your mouth is closed?

Yes 20 subjects

Q4 To identify information about dietary factors

(a) What do you like to eat?

(b) What kinds of food do you usually eat

(c) What do you like to drink

(d) What do you usually drink each day, (type and quantity)?

The responses to these questions identified that these subjects typically ate a varied and fairly balanced diet, which included fruit and vegetables. Five subjects reported a preference for junk food; it was noted that these were the older boys, possibly because they felt more confident than the younger boys, and / or because they had more opportunity to go and have the foods they preferred.

Q5 **To obtain information about environmental influences**

(a) Does it get hot / cold / dry / dusty at school.

Hot	28 subjects
Cold	No
Dry	17 subjects
Dusty	11 subjects

(b) Are you ever bother by fumes at school?

Yes 16 subjects (1 subject referred to fumes from paint, the others referred to traffic fumes, both through the open windows, and when playing in the playground).

Q6 **To obtain information about voice use**

(a) Do you play sports

If so what /how much

Does this involve much shouting

The responses to these questions are not detailed as all the boys undertook sports activities as part of the school curriculum.

Of the 23 boys who responded that they did shout during sports, 4 reported shouting a lot. Again it was noted that these four were older boys who may have felt more confident about answering honestly (since shouting was discouraged).

Q7 **To obtain information about regional influences.**

(a) How long have you lived in London

(b) Have you lived anywhere else.

These questions did provide any useful information. Any subjects who did not originally live in London had come from their home town to come to the Choir School.

Q8 **To obtain information on other factors which may influence voice**

(a) Do you play an instrument

(b) Which

(c) For how long have you been playing

(d) How often do you play

Instruments played:

Piano	*All subjects*		
Violin	*7*	*Viola*	*1*
Harp	*1*	*Organ*	*1*
Double Bass	*1*	*Percussion*	*1*
Cello	*5*	*Trombone*	*2*
Oboe	*3*	*Clarinet*	*4*
French Horn	*2*	*Bagpipe*	*1*
Flute	*2*	*Recorder*	*1*
Bassoon	*1*	*Trumpet*	*8*

Responses to questions 8c and 8d have not been detailed as they did not provide useful information and were typically very vague. Four subjects had started to learn to play the piano before coming to the school; the remained had started learning musical instruments since going to the Choir School. The average practise time was fifteen minutes a day for each instrument, although one subject reported practising for twenty six hours a week.

Q9 **To obtain information about singing**

(a) How often do you sing in the choir?
(b) How much practise do you do a day?
(c) Do you ever sing solos?
(d) Have you had singing lessons? (If yes, when, and how much)
(e) Do you find singing easy?
(f) Do you find any of the singing hard – if so, what?

It became apparent from the response to questions 9a and 9b that some choristers distinguished practise and singing in the choir, whereas others did not consider choir practise as practise, but as singing in the choir.

Responses to Q9d revealed that some choristers did not distinguish between choir practise and a singing lesson and therefore considered the choir practise a lesson.
Because of these confusions the responses to these questions have not been detailed. However when questioned further about singing lessons 16 subjects reported having one or two lessons each term; two said they had lessons before coming to the school and had lessons at home during the holiday; the remainder said they had not had singing lessons.

Q9c. 14 Subjects sang solos regularly; 4 said they sang solos occasionally.

Responses to questions 9e and 9f

Five subjects said they found singing easy, or "quite easy."

Twenty said they found it hard; of these subjects 10 reported finding the top or high notes difficult.

Two subjects identified breathing as the aspect which they found hard and one subject said he found it difficult to do solos because he felt nervous.

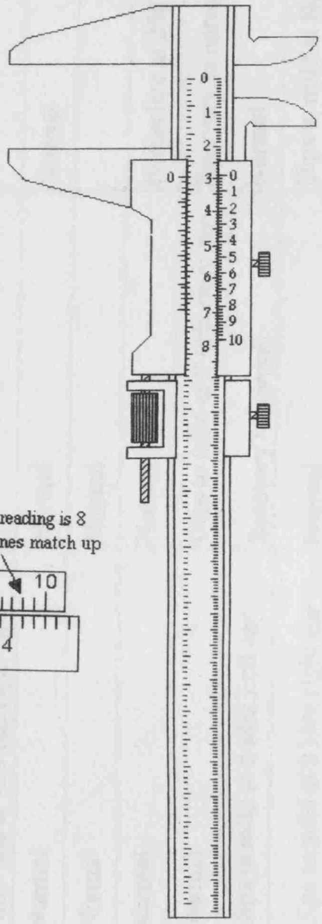
VERNIER CALIPER

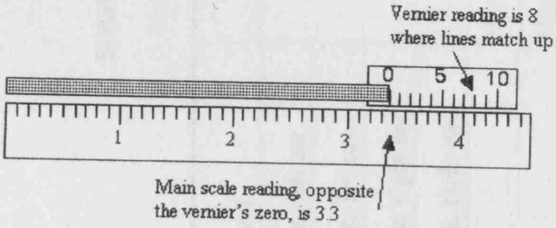
A *VERNIER* caliper is used to obtain a measure of a dimension to within 0.001cm. A fixed section of the scale is marked in increments of 0.1cm; a sliding scale is marked in increments of 0.005cm.

The measurement is derived from reading the calliper in two stages:-

- Reading the number from the main scale opposite the zero on the *Vernier* and the *Vernier* scale.
- The *Vernier* reading is the value of the mark that lines up with a main scale.

The result is the sum of the main scale and the *Vernier* reading.





Final reading 3.38 cm.

SUMMARY OF RESULTS OF AUDIOMETRIC TESTS

Subj. No	Year 1	Year 2	Year 3	Observations
3	Mild loss at 125 Hz, left ear			
4	Mild loss at 125 Hz, left ear			
6	Mild loss at 125 Hz, right ear			
7	Mild loss at 125 Hz, right ear			
12	Normal	Normal	Normal	improvement in thresholds
14	Normal	Normal		threshold worse at 2nd test
15	Normal	Normal	Borderline at 250Hz right ear	
17	Normal	Dips to mild at 8 kHz right ear	Recovery to normal	
22	Dips to mild at 8 kHz Left ear	Recovery to normal	Normal	
30	Dips to mild at 8 kHz right ear	Normal	Dips to mild at 8kHz right and left.	Fluctuating mild to normal
32	Mild dip at 125 Hz left ear	Mild dip at 125 Hz right ear		Fluctuating mild to normal

SUMMARY OF MEASURES OF HEIGHT AND WEIGHT

Subj No	Weight In relation to average for age			Height In relation to average for age			Comments
	Below	Ave	Above	Below	Ave	Above	
1			*		*		overweight
2		*			*		
3	*			*			height and weight matched
4		*			*		
5		*			*		
6	*					*	underweight
7			*	*			
8	*				*		
9			*		*		
10		*			*		
11	*			*			
12			slightly			slightly	weight : height comparable
13		*		slightly			
14	*				*		weight starting to increase to average
15		*				*	underweight for height
16			slightly		*		
17		*				*	weight ave for age.slightly underweight for ht. Increasingly above ave ht. wt increasingly in proportion.
18		*				slightly	
19		*				slightly	
20		*				*	Weight ave for age ; underweight for height
21			*			*	height and weight matched
22			slightly		*		
23	*					*	
24			*	*			increasingly overweight
25		*			*		
26		*			*		
27	*			*			height and weight matched
28			*		*		weight gain more than height
29	*			*			height and weight matched
30			*			*	height and weight matched
31			*			*	height and weight matched
32		*			*		
33			*		*		consistent
34	*			*			Height at 10.5yrs cf ave for 9.5yrs
35	*			*			very small for age
36	*					*	weight moving to match height but underweight
37		*			*		
38			*			*	weight:height appropriate
39			slighty			slightly	height and weight matched
40	*			*			slightly below ave H; very underweight

SUMMARY OF SPIROMETRY MEASURES

Subj No	Age (in years)		FVC	FEV1	FEV1/ FVC	PEFR	Height	Sitting height	Chest	Weight
		Pred Value	3.15	2.69	85	6.02				
1	12.41	Obs: Pre	3.34	2.86	86	5.56	153.6	80.8	90.5	62.4
		Obs:% Pred	106	106	101	92				
		Pred Value	3.09	2.64	85	5.94				
2	12.58	Obs: Pre	3.08	2.62	85	4.81	153.4	77.6	71.4	41.5
		Obs:% Pred	100	99	100	81				
		Pred Value	2.98	2.55	85	5.88				
3	13.29	Obs: Pre	2.27	1.99	85	5.01	151.2	79.1	69.2	40.2
		Obs:% Pred	76	78	112	85				
		Pred Value	3.40	2.91	85	6.42				
4	13.08	Obs: Pre	3.22	2.96	92	5.11	156.9	80.9	70.5	43.4
		Obs:% Pred	95	102	108	80				
		Pred Value	3.50	3.00	85	6.49				
6	12.75	Obs: Pre	3.60	3.13	92	5.57	161.6	85.2	71.4	43.1
		Obs:% Pred	103	104	108	86				
		Pred Value	2.81	2.39	85	5.64				
7	12.18	Obs: Pre	2.40	2.15	89	4.15	145.4	76.2	71.2	37.4
		Obs:% Pred	86	90	105	74				
		Pred Value	2.55	2.23	85	5.53				
	11.29	Obs: Pre	2.15	1.89	88	3.69	143.7	74.7	63.75	29.3
		Obs:% Pred	84	85	104	67				
		Pred Value	2.85	2.43	85	5.63				
8	12.28	Obs: Pre	2.56	2.03	79	3.77	148.5	76.4	64	31.9
		Obs:% Pred	90	83	93	67				
		Pred Value	3.22	2.75	85	370.9				
	13.28	Obs: Pre	2.79	2.11	76	217.5	153.1	78.6	66.7	34.8
		Obs:% Pred	87	77	89	59				
		Pred Value	2.55	2.23	85	5.53				
9	11.52	Obs: Pre	2.64	2.30	87	5.26	147.8	77.9	77.5	46.3
		Obs:% Pred	103	103	102	95				
		Pred Value	2.79	2.38	85	5.55				
10	12.09	Obs: Pre	2.46	2.24	91	4.26	150.3	78.6	74	41.4
		Obs:% Pred	88	94	107	77				
		Pred Value	2.56	2.17	85	5.24				
	11.89	Obs: Pre	2.31	2.03	88	4.97	142.5	76.1	65.1	31.5
11		Obs:% Pred	90	93	104	95				
		Pred Value	2.73	2.33	85	5.48				
	12.85	Obs: Pre	2.60	2.19	84	5.17	147	78	68	34.9
		Obs:% Pred	95	94	99	94				
		Pred Value	2.84	2.48	85	6.13				
	10.83	Obs: Pre	2.57	2.25	87	3.85	150.2	76.7	67.2	40.1
		Obs:% Pred	90	91	102	63				
		Pred Value	2.96	2.58	85	6.39				
12	11.81	Obs: Pre	2.80	2.35	84	3.71	154	80.2	76.1	50
		Obs:% Pred	94	91	99	58				
		Pred Value	3.44	2.95	85	384.4				
	12.87	Obs: Pre	3.17	2.59	82	273.5	160.6	81.7	80.7	53.9
		Obs:% Pred	92	88	96	71				

Subj No	Age (in years)		FVC	FEV1	FEV1 /FVC	PEFR	Height	Sitting height	Chest	Weight
		Pred Value	2.56	2.17	85	5.24				
13	12.48	Obs: Pre	2.30	2.26	98	5.32	144.7	75.4	66.2	36.4
		Obs:% Pred	90	104	115	101				
		Pred Value	2.85	2.43	85	5.63				
	12.02	Obs: Pre	2.28	2.04	89	5.28	149.3	77.7	61	31.2
		Obs:% Pred	80	84	105	94				
14		Pred Value	3.28	2.81	85	6.27				
	12.91	Obs: Pre	2.52	2.09	83	5.27	154.3	79.8	62.8	37.2
		Obs:% Pred	77	75	98	84				
		Pred Value	3.25	2.82	85	7.00				
	10.29	Obs: Pre	3.23	2.75	85	5.43	161.8	85.6	72	39.2
		Obs:% Pred	100	97	100	78				
		Pred Value	3.54	3.07	85	7.61				
15	11.15	Obs: Pre	3.54	3.12	87	6.03	166.1	87.6	69.8	45.1
		Obs:% Pred	100	102	102	79				
		Pred Value	4.39	3.78	85	459.2				
	12.14	Obs: Pre	3.93	3.25	83	357.8	174.5	91.9	77.5	55.3
		Obs:% Pred	90	86	98	78				
		Pred Value	2.68	2.34	85	5.79				
	11	Obs: Pre	2.79	2.39	85	4.28	145	76.1	72.1	38
		Obs:% Pred	104	102	100	74				
		Pred Value	2.76	2.41	85	5.96				
16	11.9	Obs: Pre	2.86	2.37	83	4.64	149.5	79	77.3	42.1
		Obs:% Pred	104	98	98	78				
		Pred Value	3.09	2.64	85	356.3				
	12.89	Obs: Pre	3.31	2.59	78	299.7	154	81.1	81	46.5
		Obs:% Pred	107	98	92	84				
		Pred Value	2.92	2.55	85	6.31				
	11.49	Obs: Pre	2.89	2.54	88	4.8	152.3	79.7	70.8	36.9
		Obs:% Pred	99	100	104	76				
		Pred Value	3.56	3.05	85	6.57				
17	12.67	Obs: Pre	3.48	2.95	85	6.15	162	85.2	72.5	47
		Obs:% Pred	98	97	100	94				
		Pred Value	4.22	3.64	85	450.4				
	13.42	Obs: Pre	4.77	4.23	89	521.5	172.8	79.5	77	56.5
		Obs:% Pred	113	116	104	116				
		Pred Value	2.79	2.38	85	5.55				
	11.99	Obs: Pre	2.40	2.34	98	4.70	150.5	80.2	67.5	36.5
		Obs:% Pred	86	98	115	85				
18		Pred Value	3.52	3.01	85	6.58				
	13.16	Obs: Pre	3.03	2.66	88	5.93	161.3	85.7	67.7	45.4
		Obs:% Pred	86	88	104	90				
		Pred Value	2.31	2.02	85	5.00				
	9.17	Obs: Pre	2.13	2.13	100	3.77	136.8	72.2	65	28.2
		Obs:% Pred	92	105	118	75				
		Pred Value	2.55	2.23	85	5.53				
19	10.2	Obs: Pre	2.57	2.36	92	4.84	143.3	74.2	68.5	32.1
		Obs:% Pred	101	106	108	88				
		Pred Value	2.68	2.34	85	346.8				
	11.15	Obs: Pre	2.43	2.12	87	220.9	147.4	76.3	67	33.2
		Obs:% Pred	91	91	102	64				

Subj No	Age (in years)		FVC	FEV1	FEV1 /FVC	PEFR	Height	Sitting height	Chest	Weight
20	9.6	Pred Value	2.72	2.37	85	5.87				
		Obs: Pre	1.80	1.78	99	3.73				
		Obs:% Pred	66	75	116	63				
	10.64	Pred Value	2.84	2.48	85	6.13	150.3	76.7	66.2	34.7
		Obs: Pre	2.26	2.01	89	4.46				
		Obs:% Pred	80	81	105	73				
	11.58	Pred Value	3.05	2.65	85	393.8	155.7	78.9	66.9	37.1
		Obs: Pre	2.44	2.06	84	226.2				
		Obs:% Pred	80	78	99	57				
21	10.29	Pred Value	2.55	2.23	85	5.53	144.8	78.1	69	34.1
		Obs: Pre	2.85	2.46	86	4.66				
		Obs:% Pred	111	110	101	84				
	11.34	Pred Value	2.80	2.44	85	6.05	152	82.5	70.2	38.9
		Obs: Pre	3.04	2.65	87	5.08				
		Obs:% Pred	109	109	102	84				
	12.29	Pred Value	2.97	2.53	85	346.9	155.8	81.7	74.2	42.4
		Obs: Pre	3.26	2.82	87	327.5				
		Obs:% Pred	110	111	102	94				
22	10.24	Pred Value	2.47	2.16	85	5.35	140.9	73.4	70	34.2
		Obs: Pre	2.41	1.99	82	4.32				
		Obs:% Pred	98	92	96	81				
	11.3	Pred Value	2.72	2.37	85	352.1	146	76.4		40.5
		Obs: Pre	2.46	2.18	88	232.0				
		Obs:% Pred	91	92	103	66				
	12.27	Pred Value	2.91	2.48	85	342.2	150	76.3	73.2	43.1
		Obs: Pre	2.52	2.17	86	221.1				
		Obs:% Pred	87	88	101	65				
23	8.4	Pred Value	2.35	2.06	85	5.09	139.5	74.8	68.8	30.4
		Obs: Pre	2.34	2.18	93	3.54				
		Obs:% Pred	100	106	109	70				
	9.49	Pred Value	2.60	2.27	85	5.61	147.2	76.5	69.8	33.7
		Obs: Pre	2.51	2.31	92	4.43				
		Obs:% Pred	97	102	108	79				
	10.44	Pred Value	3.17	2.75	85	409.4	159.8	77.6	69.5	35.8
		Obs: Pre	2.52	2.11	84	311.5				
		Obs:% Pred	79	77	99	76				
24	9.46	Pred Value	1.94	1.71	85	4.22	128.2	71.9	64.5	29.5
		Obs: Pre	1.68	1.62	96	4.70				
		Obs:% Pred	87	95	113	111				
	10.54	Pred Value	2.14	1.88	85	4.66	133.6	73.9	68.5	34
		Obs: Pre	2.25	2.01	89	4.30				
		Obs:% Pred	105	107	105	92				
	11.42	Pred Value	2.23	1.95	85	289.5	137	75.1	70.8	40.6
		Obs: Pre	2.27	2.02	89	316.2				
		Obs:% Pred	102	103	101	109				

Subj No	Age (in years)		FVC	FEV1	FEV1/FVC	PEFR	Height	Sitting height	Chest	Weight
		Pred Value	2.02	1.78	85	4.39				
	9.14	Obs: Pre	2.01	1.83	91	2.68	132	71.8	65.9	28.5
		Obs:% Pred	99	103	107	61				
		Pred Value	2.27	1.99	85	4.92				
25	10.12	Obs: Pre	2.64	2.31	88	4.07	137.2	73.5	68.8	31.6
		Obs:% Pred	116	116	104	83				
		Pred Value	2.35	2.06	85	305.1				
	11.02	Obs: Pre	2.66	2.31	87	230.6	141	73.5	70.9	34.3
		Obs:% Pred	113	112	102	76				
		Pred Value	2.31	2.02	85	5.00				
	9.78	Obs: Pre	1.81	1.73	96	3.26	135.3	72.1	66	28.7
		Obs:% Pred	78	86	113	65				
		Pred Value	2.39	2.09	85	5.18				
26	10.77	Obs: Pre	2.33	1.92	82	3.32	140.2	73.5	65.9	32.5
		Obs:% Pred	97	92	96	64				
		Pred Value	1.12	1.01	85	148.6				
	11.69	Obs: Pre	2.29	1.90	83	272.9	146.4	75.8	70.4	38.7
		Obs:% Pred	204	187	98	184				
		Pred Value	2.02	1.78	85	4.39				
	9.79	Obs: Pre	2.04	1.88	92	3.93	131.7	71.1	61.9	26
		Obs:% Pred	101	105	108	89				
		Pred Value	2.31	2.02	85	5.00				
27	10.81	Obs: Pre	2.33	2.06	88	3.80	135.9	72.2	64.4	28.7
		Obs:% Pred	101	102	104	76				
		Pred Value	2.31	2.02	85	299.9				
	11.12	Obs: Pre	2.31	2.00	87	280.8	137.8	72.7	66.4	29.4
		Obs:% Pred	100	99	102	94				
		Pred Value	2.35	2.06	85	5.09				
	10.01	Obs: Pre	2.29	2.14	94	5.63	140.1	76.1	69.1	38.1
		Obs:% Pred	97	104	111	111				
		Pred Value	2.47	2.16	85	5.35				
28	11.12	Obs: Pre	2.48	1.97	79	4.11	145.3	79.3	76	44.5
		Obs:% Pred	100	91	93	77				
		Pred Value	2.64	2.30	85	5.70				
	12.03	Obs: Pre	2.51	1.95	78	4.01	152.4	80.1	80.1	50.4
		Obs:% Pred	95	85	92	70				
		Pred Value	1.94	1.71	85	4.22				
	9.12	Obs: Pre	1.75	1.60	92	2.70	129.7	67.3	59	25.6
		Obs:% Pred	90	94	108	64				
		Pred Value	2.27	1.99	85	4.92				
29	10.22	Obs: Pre	1.93	1.73	90	3.37	135.4	70.3	61.5	27.4
		Obs:% Pred	85	87	106	69				
		Pred Value	2.39	2.09	85	310.3				
	11.22	Obs: Pre	2.04	1.92	94	215.9	140.2	70.8	61.9	30.6
		Obs:% Pred	85	92	110	70				
		Pred Value	2.55	2.23	85	5.53				
	9.79	Obs: Pre	2.81	2.42	86	4.21	145.5	76.5	74.3	38.6
		Obs:% Pred	110	109	101	76				
		Pred Value	2.92	2.55	85	6.31				
30	10.96	Obs: Pre	2.78	2.31	83	4.24	152.1	79.7	80.4	50
		Obs:% Pred	95	91	98	67				
		Pred Value	2.88	2.51	85	372.9				
	11.82	Obs: Pre	3.17	2.57	81	295.7	155.6	80	81	51.2
		Obs:% Pred	110	102	95	79				

Subj No	Age (in years)		FVC	FEV1	FEV1/ FVC	PEFR	Height	Sitting height	Chest	Weight
31	8.88	Pred Value	2.35	2.06	85	5.09	139.1	74.2	70	34.2
		Obs: Pre	2.53	2.18	86	4.19				
		Obs:% Pred	107	106	101	82				
	9.97	Pred Value	2.55	2.23	85	5.53	145.5	77.5	71	39.6
		Obs: Pre	2.71	2.29	84	4.64				
		Obs:% Pred	106	103	99	84				
	10.97	Pred Value	2.76	2.41	85	357.2	150.4	78.1	74	43.2
		Obs: Pre	2.95	2.58	88	321.5				
		Obs:% Pred	107	107	103	90				
32	9.39	Pred Value	2.06	1.81	85	4.48	133.2	75.7	63.6	28.9
		Obs: Pre	2.06	2.02	98	4.25				
		Obs:% Pred	100	111	115	95				
	10.48	Pred Value	2.31	2.02	85	5.00	139.1	78.2	65.8	31.4
		Obs: Pre	2.35	2.17	92	4.95				
		Obs:% Pred	102	107	108	99				
	11.48	Pred Value	2.55	2.23	85	331.2	145.7	81	72.5	37.3
		Obs: Pre	2.87	2.52	88	271.9				
		Obs:% Pred	113	113	103	82				
33	8.32	Pred Value	1.61	1.43	85	3.52	121.7	70	65	27.8
		Obs: Pre	1.63	1.46	90	2.86				
		Obs:% Pred	101	102	106	81				
	9.3	Pred Value	1.86	1.64	85	4.05	126.3	73.3	67.9	31.3
		Obs: Pre	2.22	2.09	94	3.31				
		Obs:% Pred	120	128	111	82				
	10.3	Pred Value	1.94	1.71	85	252.9	130.8	74.3	72	35.2
		Obs: Pre	1.99	1.90	96	257.9				
		Obs:% Pred	102	111	113	102				
34	8.65	Pred Value	1.82	1.61	85	3.96	126.6	67.4	59	24
		Obs: Pre	1.66	1.42	85	3.30				
		Obs:% Pred	91	88	100	83				
	9.73	Pred Value	1.98	1.75	85	4.31	131.3	70.2	61	25.6
		Obs: Pre	1.79	1.51	90	3.72				
		Obs:% Pred	90	86	106	86				
34	10.73	Pred Value	2.19	1.92	85	284.2	136.2	70.8	66	28.7
		Obs: Pre	2.00	1.63	81	157.1				
		Obs:% Pred	92	85	95	55				
35	8.1	Pred Value	1.53	1.36	85	3.35	119.4	65.2	56.4	19.8
		Obs: Pre	1.62	1.42	87	2.57				
		Obs:% Pred	106	104	102	77				
	8.98	Pred Value	1.70	1.50	85	221.6	123.2	67.2	58.2	21.7
		Obs: Pre	1.94	1.61	83	176.4				
		Obs:% Pred	114	107	98	80				
	10.02	Pred Value	1.86	1.64	85	242.5	126.8	67.7	61	24.2
		Obs: Pre	1.75	1.64	93	245.1				
		Obs:% Pred	94	100	109	101				
36	9.38	Pred Value	2.76	2.41	85	5.96	151.1	79.9	68.5	38.3
		Obs: Pre	2.91	2.56	88	4.72				
		Obs:% Pred	106	106	104	79				
	10.39	Pred Value	3.13	2.72	85	6.74	157.5	82.2	74.2	45.8
		Obs: Pre	2.91	2.59	89	3.99				
		Obs:% Pred	93	95	105	59				
	11.41	Pred Value	3.33	2.89	85	430.2	164.5	84.8	83	55.2
		Obs: Pre	3.28	2.78	85	310.5				
		Obs:% Pred	98	96	100	72				

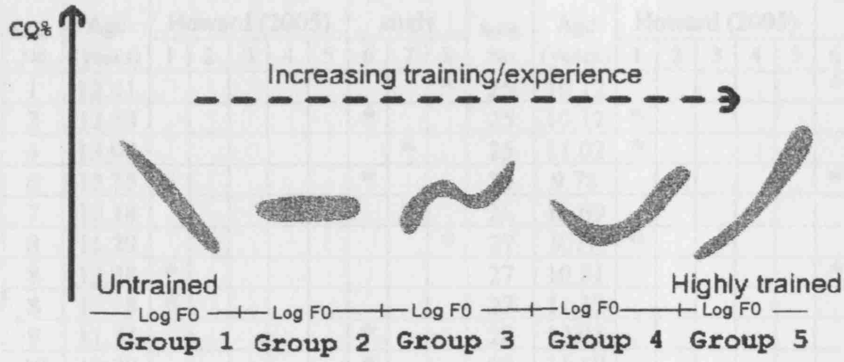
Subj No	Age (in years)		FVC	FEV1	FEV1 /FVC	PEFR	Height	Sitting height	Chest	Weight
37	8.75	Pred Value	2.11	1.85	85	4.57	131.6	71	61	27.4
		Obs: Pre	2.41	1.88	78	3.48				
		Obs:% Pred	115	102	92	76				
	9.8	Pred Value	2.39	2.09	85	310.3	146.9	73.6	60	30.7
		Obs: Pre	2.61	2.02	78	236.6				
		Obs:% Pred	109	97	92	76				
38	8.47	Pred Value	2.23	1.95	85	4.83	135	72.3	65.3	31.7
		Obs: Pre	2.53	2.16	86	4.45				
		Obs:% Pred	113	111	101	92				
	9.48	Pred Value	2.60	2.27	85	336.4	141	76	72.4	36.7
		Obs: Pre	2.85	2.33	82	182.4				
		Obs:% Pred	110	103	96	54				
39	8.24	Pred Value	2.19	1.92	85	4.74	134	72.8	62.1	29.4
		Obs: Pre	2.08	2.00	96	4.41				
		Obs:% Pred	95	104	113	93				
39	9.28	Pred Value	2.39	2.09	85	310.3	140.1	76.3	65.2	
		Obs: Pre	2.51	2.20	88	249.6				
		Obs:% Pred	105	105	103	80				
	10.48	Pred Value	2.64	2.30	85	341.6	146.8	78.1	68.5	37.4
		Obs: Pre	2.63	2.30	87	286.1				
		Obs:% Pred	100	100	102	84				
40	8.01	Pred Value	1.57	1.4	85	3.44	123.1	66.5	55	21.1
		Obs: Pre	1.35	1.21	93	1.73				
		Obs:% Pred	86	87	109	50				
	8.99	Pred Value	2.06	1.81	85	268.6	133.7	69.8	59.6	25.6
		Obs: Pre	1.73	1.42	82	255.7				
		Obs:% Pred	84	78	96	95				

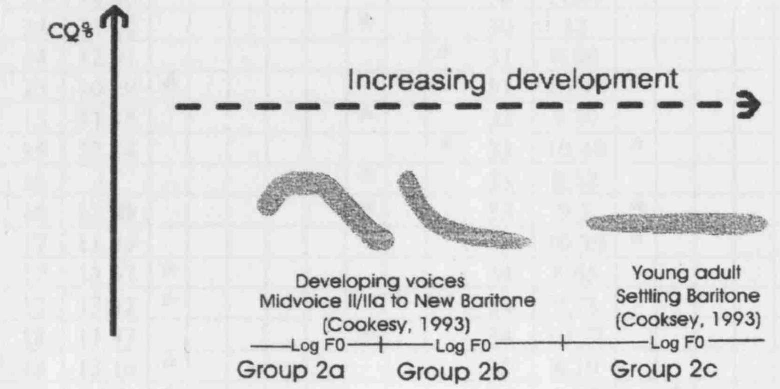
DETAILS OF SUBJECTS WHO PLAY A WIND INSTRUMENT							
Subj No	Age (in years)	Instrument played	Learning for (time in yrs)	Subj No	Age (in years)	Instrument played	Learning for (time in yrs)
3	13.29	Oboe	3.5	20	9.6	Bassoon	0.1
27	9.79		1	16	11	Clarinet	3
30	9.79		1	26	9.78	Clarinet	2
32	9.39	Recorder	2	28	10.01	Clarinet	1.5
18	11.99	Trumpet	3	19	9.17	Clarinet	1
1	12.41		3.5	10	12.09	Flute	3
23	8.14		2	25	9.14		1
31	8.88		1	13	12.48	French Horn	2
36	9.38		0.5	11	11.89	Trombone	3
12	10.83		3	21	10.29		4
14	12.02	Bagpipes	1				

EXAMPLES OF CLASSIFICATION OF HISTORGRAMS

Subj No	Age	Material	DFx1											DFx2																		Octave Range	
			S	A	AL	AH	N	W	Ave	MH	ML	EH	EL	S	A	AL	AH	N	W	Ave	EH	EL	W	Ave	N	L	H	Mid	D	B	P	DFx1	DFx2
		Read			*			*				*	*			*					*		*						*			0.8	0.7
4	13	Speech			*			*		*			*		*					*					*	*						0.7	0.6
		Sing			*				*		*					*								*				*				1.0	0.9
		Read			*				*				*			*				*					*	*						0.5	0.4
6	13	Speech				*			*				*	*				*			*				*							0.5	0.4
		Sing			*				*		*					*				*												0.9	0.8
		Read			*			*			*					*			*		*					*					*	2.3	0.8
1	12	Speech			*			*			*	*				*				*	*				*	*						1.2	0.5
		Sing			*				*		*					*				*				*					*	*		2.0	1.1
		Read			*			*			*	*				*			*		*			*					*		*	1.0	0.8
18	12	Speech			*		*				*					*		*			*				*	*					*	1.2	0.3
		Sing				*		*						*										*			*		*			1.3	1.3
		Read		*				*				*	*		*				*		*		*						*		*	1.1	0.9
8	11	Speech			*			*								*				*				*		*						0.5	0.5
		Sing	*							*	*													*								1.0	0.9
		Read		*					*	*		*			*					*	*			*		*						0.8	0.6
12	11	Speech			*			*				*				*			*				*									1.0	0.9
		Sing		*		*				*							*							*			*					1.0	1.0
		Read		*				*			*	*				*			*		*		*			*	*				*	1.6	0.7
15	10	Speech		*				*		*	*			*				*		*	*		*							*	*	1.8	0.5
		Sing		*		*		*									*							*			*	*				1.0	0.6
		Read		*					*		*	*			*					*	*			*						*	*	1.0	0.5
26	9.8	Speech		*							*				*			*			*			*		*				*	*	1.3	0.4
		Sing				*			*					*						*				*		*			*			1.0	0.8
		Read			*				*			*				*				*	*			*								0.6	0.5
25	9.1	Speech	*					*		*		*	*			*					*	*		*					*			0.6	0.5
		Sing				*	*										*	*							*			*				0.6	0.5
		Read	*									*		*							*			*		*						0.6	0.5
31	8.9	Speech		*					*		*				*			*			*	*			*	*					*	1.4	0.4
		Sing				*		*									*			*				*					*			2.0	0.8
		Read	*						*				*	*					*	*	*	*		*					*			0.7	0.5
35	8.1	Speech		*				*				*	*			*			*						*	*						1.3	0.8
		Sing	*						*					*						*				*					*			0.9	0.8

IDEALIZED MODEL OF Qx PLOTS





From: Barlow and Howard (2005)

CLASSIFICATION OF QxFx PLOTS

SPEECH																			
Subj. No	Age (years)	Barlow and Howard (2005)					The present study			Subj. No	Age (years)	Barlow and Howard (2005)					The present study		
		1	2	3	4	5	6	7	8			1	2	3	4	5	6	7	8
1	12.41								*	25	10.12						*		
2	12.58						*			25	10.12	*							
4	13.08							*		25	11.02	*							
6	12.75						*			26	9.78						*		
7	12.18							*		26	11.69								*
8	11.29								*	27	9.79	*							
8	12.28	*								27	10.81						*		
8	13.28	*								27	11.12							*	
9	11.52						*			28	10.01							*	
10	12.09						*			28	11.12								*
11	11.89							*		28	12.03						*		
11	12.85						*			29	9.12				*				
12	10.83				*					29	10.22		*						
12	11.81						*			29	11.22		*						
12	12.87						*			30	9.79						*		
13	12.48						*			30	11.09								*
14	12.02						*			30	12						*		
14	12.91								*	31	8.88						*		
15	10.29	*								31	10.97	*							
15	11.15						*			32	9.39						*		
15	12.14								*	32	10.48	*							
16	11						*			33	8.32						*		
16	12.89						*			33	9.3	*							
17	11.49						*			33	10.30	*							
17	12.67	*								34	8.65						*		
17	13.42	*								34	9.73						*		
18	11.97						*			34	10.73						*		
18	13.16	*								35	8.10						*		
19	10.2	*								35	8.98		*						
19	11.15	*								35	10.02	*							
20	10.64						*			36	9.38					*			
20	11.58						*			36	10.39	*							
21	10.29						*			36	11.41	*							
21	11.34						*			37	8.75						*		
21	12.29	*								37	9.8	*							
22	10.24						*			37	10.68						*		
22	11.3						*			38	8.47						*		
22	12.27							*		38	9.48						*		
23	9.49	*								38	10.48	*							
23	10.40	*								39	8.24						*		
24	10.54						*			39	9.28						*		
24	11.42						*			39	10.48						*		
25	9.14	*								40	8.01						*		
25	9.14	*								40	9.99	*							

READING																			
Subj. No	Age (years)	Barlow and Howard (2005)					The present study			Subj. No	Age (years)	Barlow and Howard (2005)					The present study		
		1	2	3	4	5	6	7	8			1	2	3	4	5	6	7	8
1	12.41								*	26	9.78	*							
2	12.58	*								26	10.77	*							
4	13.08	*								26	11.69					*			
6	12.75	*								27	9.79	*							
7	12.18						*			27	10.81							*	
8	11.29	*								27	11.12	*							
8	12.28	*								28	10.01				*				
8	13.28	*								28	11.12					*			
9	11.52						*			28	12.03					*			
10	12.09						*			29	9.12	*							
11	11.89	*								29	10.22		*						
11	12.85					*				29	11.22	*							
12	10.83	*								30	9.79						*		
12	11.81	*								30	11.09						*		
12	12.87	*								30	12						*		
13	12.48						*			31	8.88						*		
14	12.02					*				31	9.97						*		
14	12.91	*								31	10.97						*		
15	10.29						*			32	9.39						*		
15	11.15							*		32	10.48				*				
15	12.14	*								32	11.48	*							
16	11	*								33	8.32	*							
16	11.9							*		33	9.3						*		
16	12.89	*								33	10.30	*							
17	11.49						*			34	8.65						*		
17	12.67	*								34	9.73	*							
17	13.42	*								34	10.73	*							
18	11.99						*			35	8.1						*		
18	13.16	*								35	8.98					*		*	
19	10.2	*								35	10.02								*
19	11.15				*					36	9.38		*						
20	10.64						*			36	10.39	*							
20	11.58	*								36	11.41	*							
21	10.29					*				37	8.75						*		
21	11.34					*				37	9.8	*							
21	12.29						*			37	10.68	*							
22	10.24						*			38	8.47	*							
22	11.3	*								38	9.48						*		
22	12.27						*			38	10.48	*							
23	9.49	*								39	8.24		*						
23	10.40	*								39	9.28	*							
24	10.54						*			39	10.48	*							
24	11.42							*		40	8.01						*		
25	9.14	*								40	8.99						*		
25	10.12	*								40	9.99						*		
25	11.02				*														

SINGING																			
Subj. No	Age (years)	Barlow and Howard (2005)					The present			Subj. No	Age (years)	Barlow and Howard (2005)					The present		
		1	2	3	4	5	6	7	8			1	2	3	4	5	6	7	8
1	12.41						*			26	10.77						*		
2	12.58		*							26	11.69				*		*		
4	13.08	*								26	11.69				*				
6	12.75	*								27	9.79							*	
7	12.18					*				27	10.81		*						
8	11.29								*	27	11.12		*						
8	12.28					*				28	10.01		*						
8	13.28							*		28	11.12					*			
9	11.52						*			28	12.03		*						
10	12.09				*					29	9.12	*							
11	11.89		*							29	10.22		*						
11	12.85				*					29	11.22		*						
12	10.83				*					30	9.79	*							
12	11.81				*					30	11.09					*			
12	12.87							*		30	12					*			
13	12.48						*			31	8.88				*				
14	12.02						*			31	9.97					*			
14	12.02						*			31	10.97	*							
14	12.91									32	9.39						*		
15	10.29		*							32	10.48		*						
15	12.14						*			32	11.48				*				
16	11	*								33	8.32	*							
16	11.9						*			33	9.3		*						
16	12.89	*								33	10.30					*			
17	11.49						*			34	8.65	*							
17	12.67		*							34	9.73				*				
17	13.42	*								34	10.73				*				
18	11.97						*			35	8.1		*						
18	13.16		*							35	8.98		*						
19	10.2				*					35	10.02				*				
19	11.15							*		36	9.38						*		
20	10.64	*								36	10.39								
20	11.58		*							36	11.41		*						
21	10.29						*			37	8.75								
21	11.34						*			37	8.75		*						
21	12.29		*							37	9.8			*					
22	10.24									37	10.68			*					
22	10.24	*								38	8.47	*							
22	11.3		*							38	9.48				*				
22	12.27		*							38	10.48		*						
23	9.49								*	39	8.24					*			
23	10.44								*	39	9.28	*							
25	9.14				*					39	10.48				*				
25	10.12	*								40	8.01					*			
25	11.02		*							40	9.99					*			
26	9.78	*																	

	Subj. No	Age (in years)	Barlow and Howard (2005)					The present study			Subj. No	Age (in years)	Barlow and Howard (2005)					The present study		
			1	2	3	4	5	6	7	8			1	2	3	4	5	6	7	8
SCALES	39	8.24		*							12	10.83				*				
	35	8.98				*					31	10.97					*			
	29	9.12		2A							27	11.12				*				
	25	9.14					*				29	11.22		*						
	39	9.28	*								8	11.29		*		*				
	38	9.48		*							21	11.34		*						
	23	9.49	*								17	11.49	*							
	27	9.79				*					11	11.89		*						
	37	9.8		*							14	12.02	*							
	35	10.02		*							8	12.28	*							
	25	10.12	*								21	12.29	*							
	19	10.2		*							1	12.41					*			
	29	10.22	*								2	12.58	*							
	15	10.29			*						11	12.85		*						
	38	10.48	*			*					12	12.87					*			
	39	10.48	*								14	12.91	*							
	20	10.64		*							4	13.08	*							
	37	10.68					*				18	13.16		*	*					
	27	10.77		*							17	13.42							*	
	27	10.81				*														
ASCENDING GLIDE	1	12.41								*	29	10.22		2A						
	8	11.29	*								31	10.97					*			
	8	12.28			*						35	8.1		*						
	8	13.28								*	35	8.98			*					
	11	12.85			*						36	9.38	*							
	12	10.83	*								36	10.39		*						
	12	12.87				*					37	8.75								
	14	12.02		*							37	8.75			*					
	15	10.29				*					37	9.8			*					
	15	11.15	*								38	9.48								
	17	12.67								*	39	8.24	*							
	17	13.42	*								39	9.28	*							
	18	13.16		*			*				39	10.48							*	
	20	10.64					*				23	10.44	*							
	20	11.58				*					27	11.12							*	
	21	10.29		*							31	8.88								
	21	12.29								*	35	10.02		*						
	25	10.12								*	37	10.68			*					
	27	9.79								*	38	8.47	*							
	29	9.12	*																	
DESCENDING GLIDE	1	12.41						*			31	8.88					*			
	8	11.29						*			31	10.97							*	
	8	12.28							*		35	8.1				*				
	11	12.85			*						35	8.98	*							
	12	10.83	*								36	9.38	*							
	12	12.87					*				37	8.75						*		
	14	12.02	*								37	8.75					*			
	15	11.15			*						37	9.8					*			
	17	12.67			*						38	8.47		2A						
	17	13.42	*								38	9.48		*						
	20	10.64	*								39	8.24	*							
	21	10.29		*							39	9.28	*							
	27	9.79	*								39	10.48				*				
	29	9.12		2A	*															

SUMMARY OF PERCEPTUAL EVALUATION

Subj No	Age (Years)	Voice Quality Features: Rough	Breathy	Asthenia	Strain	Hard	Pitch	Comments
1	12.41		a					creaky quality on low vowels
2	12.58		a			*		
4	13.08						low	pitch lowering; minimal breaks. Good resonance.
6	12.75							No discernible features
7	12.18		c					breathy quality on low frequencies
8	11.29		a					
	12.28							more resonant than previous recording
	13.28		c					voice stronger than previous year
9	11.52				c			Hyponasal
10	12.09							No discernible features
11	11.89			b	b	*		
	12.85		a				lower	voice stronger
12	10.83							no discernible features
	11.81							more resonant
	12.87		b				lower	
13	12.48	a	a		a			throat clearing; poor breath support
14	12.02		b			*		Breathy quality more evident on upper frequencies
	12.91					*	lower	Voice stronger, more resonant; no breathiness
15	10.29		a		a	*		Breathy quality more evident at end of tasks
	11.15					*		
	12.14							
16	11					*		No discernible features
	11.9					*	lower	
	12.89					*	lower	
17	11.49					*		No discernible features
	12.67					*	lower	
	13.42				a		lower	Voice stronger
18	11.99							No discernible features
	13.16		b			*	lower	Breathy quality on high frequencies
19	10.2					*		
	11.15							

SUMMARY OF PERCEPTUAL EVALUATION

Subj No	Age (Years)	Voice Quality Features						Comments
		Rough	Breathy	Asthenia	Strain	Hard	Pitch	
20	9.60					*		
	10.64		b	b		*		
	11.58		c			*		
21	10.29	a	b			*		
	11.34							much lower
	12.29						lower	
22	10.24	a	b		a	*		
	11.3		a			*		Voice stronger
	12.27		b				lower	
23	8.14							No discernible features
	9.49							
	10.40							
24	9.46							No discernible features
	10.54							
	11.42							
25	9.14				a	*		
	10.12					*		Strain end of utterance ; poor breath support
	11.02		a					Increased resonance on low frequencies
26	9.78					*		
	10.77							Hyponasal
	11.69						lower	
27	9.79		a					
	10.81		b				lower	
	11.12		c				lower	throat clearing
28	10.01	c	c			*		Voice quality consistently rough
	11.12	c	c					
	12.03	c	c				lower	
29	9.12		b					hesitatiion reading
	10.22	a	a					
	11.22					*		throat clearing
30	9.79							
	11.09		b					
	12							

SUMMARY OF PERCEPTUAL EVALUATION

Subj No	Age (Years)	Voice Quality Features						
		Rough	Breathy	Asthenia	Strain	Hard	Pitch	Comments
31	8.88						high	
	9.97		a				lower	
	10.97					*	lower	Voice stronger
32	9.39			a				very distinct articulation
	10.48		b					
	11.48						lower	Increased resonance
33	8.32			a		*		
	9.3					*		
	10.30		c				lower	
34	8.65		c	c				Voice sounded like that of a little girl
	9.73							
	10.73						lower	
35	8.1			a		*		Hyponasal
	8.98							
	10.02							
36	9.38					*		
	10.39		b	a			lower	
	11.41		a				lower	Voice stronger
37	8.75		a	a		*		Reading word by word - hesitant
	9.8		b			*	lower	Voice more resonant. Throat clears
	10.68		c			*	lower	Voice sounding stronger
38	8.47							
	9.48							
	10.48		c				lower	
39	8.24					*		
	9.28							
	10.48		b					
40	8.01	a	b	c				very 'small' voice; sounds younger than age
	8.99		c	c		*		Noticeably breathy quality
	9.99		b	a		*		